U.S. Department Of Transportation

National Highway Traffic Safety Administration

NHTSA

PRELIMINARY REGULATORY IMPACT ANALYSIS

FMVSS No. 150
Vehicle-To-Vehicle Communication Technology
For
Light Vehicles

Office of Regulatory Analysis and Evaluation

National Center for Statistics and Analysis

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People Saving People

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EXECUTIVE SUMMARY

The National Highway Traffic Safety Administration (NHTSA or the agency) is proposing to establish Federal Motor Vehicle Safety Standard (FMVSS) No. 150, Vehicle-to-Vehicle (V2V) Communication Systems. The proposed rule would require passenger cars, multipurpose passenger vehicles (MPVs), trucks, and buses having a gross vehicle weight rating (GVWR) of 4,536 kilograms (kg; 10,000 pounds) or less to be equipped with V2V communication technology, such that they will send and receive Basic Safety Messages (BSMs) to and from other vehicles. This Preliminary Regulatory Impact Analysis (PRIA) accompanies the Notice of the Proposed Rulemaking (NPRM) for establishing the FMVSS No. 150.

The proposed rule is complex and covers a wide range of areas; some are outside of the agency traditional regulatory boundary. The primary covered areas include communication technology, BSM format and communication protocols, spectrum use, BSM authentication, misbehavior detection and reporting, cybersecurity, and consumer privacy. Specifically, in communication technology, BSM authentication, and, misbehavior detection and reporting, the agency is trying to be comprehensive for each of these areas.

For V2V communication, the agency proposes to mandate dedicated short range communication (DSRC) technology while also allowing provisions for alternative technologies that are interoperable with DSRC as the agency recognizes the potential for innovation from other wireless communication technologies.

The requirements for message authentication, misbehavior detection and reporting are to ensure a secure communication environment. For message authentication, the agency proposes that all V2V devices sign and verify their basic safety messages using a Public Key Infrastructure (PKI) –based Security Credential Management System (SCMS) in accordance with performance requirements and test procedures for BSM transmission and the signing of BSMs. In addition, the agency considers two alternatives. The first alternative is that the agency does not specify architecture or technical requirements for message authentication. Under this alternative, a receiver of a BSM message must be able to validate the contents of a message such that it can reasonably confirm that the message originated from a single valid V2V device, and the message was not altered during transmission. The second alternative is that the agency does not propose a specific message authentication requirement. BSM messages would still be validated with a checksum, or other integrity check, and be passed through a misbehavior detection system to attempt to filter malicious or misconfigured messages. Implementers would be free to include message authentication as an optional function. .

For the misbehavior detection and reporting, the agency proposes to mandate requirements that would establish procedures for communicating with a SCMS (PKI or other system) to report misbehavior; and learn of misbehavior by other participants. This includes detection methods for a device hardware and software to ensure that the device has not been altered or tampered with from intended behavior. The alternative we proposed is that the agency would not to issue the requirement to report misbehavior or implement device blocking based to an authority. However, this proposed alternative would require implementers to identify methods that check a devices' functionality, including hardware and software, to ensure that the device has not been altered or tampered with from intended behavior. Implementers would be free to include misbehavior detection and reporting and as optional functions.

In addition, the agency's research on authentication and misbehavior detection and reporting had been based on a PKI-based SCMS (i.e., the main proposal for these areas). Therefore, this PRIA examines only the potential safety impacts and costs of the proposed rule for DSRC technology and PKI-based SCMS (DSRC/PKI-based proposal in short). **(For streamlining the discussion, the "proposed rule" is referring to DSRC/PKI-based proposal, hereafter**. All discussions unless noted otherwise on proposed requirements are for this proposal.)

Although we did not estimate the benefits for potential V2V communication technologies other than DSRC, the agency believes that the estimated benefits for DSRC are applicable to other technologies if these technologies can meet the proposed DSRC performance requirements. By contrast, the agency is less certain on whether the estimated costs for DSRC/PKI-based proposal would be comparable to that of alternative interoperable technologies approach due to a greater uncertainty on technology type, the message authentication strategy, and associated cost factors such as hardware, security, cost structure, etc.).

DSRC is a Wi-Fi type two-way short to medium-range communication system using radio frequencies. In relation to DSRC, FCC has specified that BSM transmissions and reception will occur on channel 172, i.e. channel 172 will be dedicated to all BSM communications (safety-critical communications). Therefore, throughout this document, references to BSM transmissions and reception will refer to channel 172 while also recognizing the ongoing DOT-FCC-NTIA spectrum sharing studies and the FCC rulemaking concerning the 5.9 GHz band as described in more detail below. When implemented, vehicles can transmit and receive safety-critical messages to and from surrounding vehicles using the radio channel 172 (frequencies 5.855-5.865 gigahertz (GHz) within the 5.850-5.925 GHz frequency band (the 5.9 GHz band with a total 75 Megaherts (MHz)). Channel 172, a 10 MHz band, was designated by the Federal Communications Commission (FCC) in 2003 to be exclusively used for vehicle-to-vehicle safety communications for accident avoidance and mitigation, and safety of life and property applications.[1] The 5.9 GHz band that DSRC is operated on has low latency and high reliability characteristics. Therefore, DSRC is an appropriate technology solution for enabling communication-based safety applications suitable specifically for the dynamic traffic/roadway environment. Furthermore, DSRC has a 300-meter transmitting range and a 360-degree unobtrusive detection angle that surpass the sensing capability of sensors, cameras, and radars currently used in vehicles (i.e., vehicle-resident). Although NHTSA is not mandating any V2V-based safety applications (apps) at this time, we expect that vehicles will gradually be equipped with these apps as an increasing number of vehicles are DSRC equipped. V2V-based safety apps will directly reduce the number and severity of motor vehicle crashes and minimize the societal costs resulting from these crashes. Despite decades of safety efforts and safety advances, about 5.5 million vehicle crashes and 32,995 fatalities still occurred in 2013.[2] The proposed rule ushers a new era of vehicle safety.

[1] Amendment of the Commission's Rules Regarding Dedicated Short-Range Communication Services in the 5.850-5.925 GHz Band (5.9 GHz Band), WT Docket No. 01-90, December 17, 2003

[2] National Highway Traffic Safety Administration, Fatality Analysis Report System (FARS) 2013 data. For more information, see www.nhtsa.gov/FARS

The potential safety benefits of the proposed rule include reductions in fatalities, injuries, and property-damage-only vehicles.[3] The estimated quantified costs include V2V vehicle technology costs, the cost for infrastructure for a seamless and secure operational environment, the cost of vehicle-to-infrastructure communication, and fuel economy impact due to the additional weight from the required in-vehicle components. Benefits and costs were estimated in two measures: calendar year-based (i.e., annual measures) and model year-based (i.e., MY measures). The annual measures represent the effects that would be accrued collectively by all V2V-vehicles in a calendar year. These measures are not discounted. The MY measures, in contrast, estimate the effects over the life of a vehicle[4] and were discounted at 3 percent and 7 percent to reflect their present value.

The benefit and cost estimates were used in the breakeven, cost-effectiveness, and net-benefit analyses to determine several cost-beneficial milestones of the proposed rule. The breakeven analysis determines the year that the total investment of the proposed rule will be paid back through the total realized benefits. The cost-effectiveness and net-benefit analyses determine the MY vehicles that would become cost-effective and accrue positive net benefits.

In addition to the proposed rule, the PRIA also examined the impact of two regulatory alternatives that are also based on DSRC/PKI. One regulatory alternative requires both the V2V communication capability and two safety apps that provide warnings to the driver of impending crashes. The other alternative would allow manufacturers to voluntarily equip their vehicles with V2V technology that complies with specified performance requirements. The second alternative is also called “If-equipped” alternative in the PRIA.

As mentioned, the costs and benefits were estimated by considering a scenario where manufacturers would, in addition to the DSRC technology, voluntarily install two safety apps

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[3] Vehicles that were damaged but no injuries or fatalities occurred in the vehicles

[4] 30 years for passenger cars and 37 years for light trucks and vans

that currently are deemed to be enabled only by V2V. These two safety apps are Intersection Movement Assist (IMA) and Left Turn Assist (LTA). We believe this scenario is reasonable because the incremental cost of IMA and LTA is less than one percent of the DSRC costs and the industry has indicated that these two apps are already in their research and deployment plan. Moreover, we believe that this scenario is likely to understate benefits because manufacturers may choose to offer other safety apps that use V2V technology beyond these two, as well as various other technologies that use DSRC, such as vehicle-to-infrastructure (V2I) or vehicle-to-pedestrian (V2P) technologies.

The base calendar year and MY for the analysis is 2021, the projected first year of implementation of the proposed rule. The monetized values, if not otherwise specified, are expressed in 2014 dollars. The annual measures (i.e., annual benefits, annual costs, etc.) are presented for 40 years from 2021 to 2060. The MY measures are presented for 30 MYs (MY 2021 to MY 2050).[5] Furthermore, in this analysis, a MY vehicle production represents the new vehicle production volume for the calendar year with the same number. The MY sales volume was used as the base for estimating the annual costs for that specific calendar year. For example, MY 2021 vehicle production volume is used to estimate the costs for 2021.

Requirements

The proposed rule would require light vehicles with a gross vehicle weight rating (GVWR) of 4,536 kg (10,000 pounds) or less to have V2V communication capability using an on-board DSRC device to transmit and receive standardized basic safety messages (BSMs) meeting the performance requirements specified in FMVSS No. 150. All in-vehicle equipment requirement discussions later in this document are based on the DSRC technology.

To ensure interoperability, security, privacy, and seamless V2V operation, the proposed rule specifies (1) the performance of a DSRC device (DSRC radios), (2) the content, structure, and accuracy of the BSM as well as the transmitting protocol, (3) BSM authentication requirements,

[5] MY 2050 benefits would be realized from year 2050 to 2086.

(4) misbehaver detection and reporting requirements to prevent bad actors from interrupting operations, and (5) a consumer privacy notice to inform consumers of what data is being transmitted in V2V communications, how V2V systems use safety messages, who else may collect and use V2V communications, and to provide other privacy information to consumers in furtherance of the Fair Information Practice Principles (FIPPs). The proposed rule also requires manufacturers to install a V2V malfunction telltale (warning lamp) using specific symbols and/or text for the malfunction telltale. In addition, an On/Off switch to turn off V2V communication would not be allowed.

In order to ameliorate the implementation costs to the industry, the agency is proposing a three-year phase-in schedule that would be effective two years after the proposed rule is finalized. The phase-in schedule as proposed would require 50 percent of light vehicles to have the DSRC communication capability in the first year of the phase-in, 75 percent in the second year, and 100 percent in the third year.

The agency does not propose mandating apps at this time and instead encourages a free-market approach to adoption of apps. Basically, the agency intends to lay the foundation for a new technology that would address the limitations of vehicle-based sensing technologies and to facilitate the implementation of V2V-based apps for improving vehicle safety, mobility, and environmental sustainability. However, the agency is examining the need for performance standards and test procedures for the IMA and LTA safety applications and requests comment on any available information the public has concerning these issues.

V2V System and Operation

A V2V system as currently envisioned would be a combination of many elements. This includes a radio technology for the transmission and reception of messages, the structure and contents of "basic safety messages" (BSMs), the authentication of incoming messages by receivers, and, depending on a vehicle's behavior, the triggering of one or more safety warnings to drivers. The agency is also proposing to require that vehicles be capable of receiving over-the-air (OTA) security and software updates (and to seek consumer consent for such updates where appropriate). In addition, NHTSA is also proposing that vehicles contain "firewalls" between V2V modules and other vehicle modules connected to the data bus to help isolate V2V modules being used as a potential conduit into other vehicle systems. The NPRM presents a comprehensive proposal for mandating DSRC-based V2V communications. That proposal includes a pathway for vehicles to comply using non-DSRC technologies that meet certain performance and interoperability standards. A key component of interoperability is a "common language" regardless of the communication technology used. Therefore, the agency's proposal includes a common specification for basic safety message (BSM) content regardless of the potential communication technology. The proposal also provides potential performance-based approaches for two security functions in an effort to obtain reaction and comment from industry and the public.

Technical Feasibility

The agency is confident that the required V2V communication technology is feasible for new light vehicles based on the DOT's research results and on the industry's public announcements on this technology. Specifically, the DOT sponsored Safety Pilot Model Deployment (Model Deployment) demonstrated the basic interoperability among several vehicle types, vehicle models, and production lines.[6]

Furthermore, based on the industry's public announcements, V2V technology apparently is moving from the research phase into the deployment phase. GM already announced that they will implement the V2V technology in some of their 2017 model vehicles.[7] Therefore, the agency believes that the V2V technology can be implemented in the proposed timeframe.

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[6]The Model Deployment is a scientific research initiative that features a real-world implementation of connected vehicle safety technologies, applications, and roadway infrastructure using everyday drivers. Six V2V apps were tested in the Model Deployment: Intersection Movement Assist (IMA), Left-Turn Assist (LTA), Forward Collision Warning (FCW), Blind Spot Warning/Land Change Warning (BSW/LCW), Enhanced Emergency Break Warning (EEBW), and Do Not Pass Warning (DNPW). It ran from August 2012 to February 2014 in Ann Arbor, Michigan.

[7] GM News, Cadillac to Introduce Advanced 'Intelligent and Connected' Vehicle Technologies on Select 2017 Models, Super Cruise and V2V technologies slated for production in about two years," September, 07, 2014

Technology Adoption Schedule

Table E-1 shows the technology adoption scenario assumed in the analysis. The DSRC adoption rates were based on the proposed phase-in schedule. The app adoption rates were the agency's projection for two safety apps IMA and LTA, which is based on the agency's contracted study on V2V market deployment, NCAP data, announcements from the industry, and our conversations with several vehicle manufacturers on the development of V2V. The PRIA estimated the benefits and costs based on this adoption scenario.

Table E-1
V2V Technology Adoption Rates in Percent

	Model Year							
	2021	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**
DSRC	50	75	100	100	100	100	100	100
Apps*	0	5	10	25	40	65	90	100

*as percent of DSRC-equipped vehicles

Projected On-Road Vehicles That Would Have the V2V Technology

Based on the adoption scenario stated above, the agency projects that in 2021, approximately 8.1 million light vehicles (3.3 percent of on-road light vehicles) would have the DSRC radios as shown in Table E-2. But, none of these vehicles are expected to have the IMA and LTA apps. In 2030, about 144.3 million light vehicles would be installed with DSRC radios. This is equivalent to 55.8 percent of the on-road light vehicles. The agency estimates that about 87.2 million vehicles (33.7 percent) would have the two safety apps. In 2050, over 96 percent of on-road light vehicles would have DSRC radios and the two safety apps. Table E-2 shows the projected on-road light vehicles that would have the V2V Technology.

Table E-2
Projected On-Road Light Vehicles That Would Have the V2V Technology

Year	Calendar Year	With DSRC Radios		With Apps	
		Number of Vehicles (Million)	Percent	Number of Vehicles (Million)	Percent
1	2021	8.1	3.3%	0.0	0.0%
5	2025	68.13	27.4%	6.3	5.2%
10	2030	144.3	55.8%	87.2	33.7%
15	2035	208.4	77.6%	163.7	61.0%
20	2040	253.0	90.8%	226.1	81.2%
25	2045	276.6	96.2%	265.3	92.3%
30	2050	291.3	98.6%	286.9	96.8%
35	2055	300.6	99.7%	298.1	98.9%
40	2060	305.2	100.0%	304.6	99.8%

Annual Benefits

The agency estimated the potential benefits of the proposed rule based on a scenario where two safety apps, IMA and LTA, are voluntarily adopted by industry following a mandate. The agency focused on these two apps because we have sufficient data for these apps and because they can be currently effectively enabled only by V2V. The IMA app warns drivers of vehicles approaching from a lateral direction at an intersection, while LTA warns drivers of vehicles approaching from the opposite direction when attempting a left turn at an intersection. The agency notes that manufacturers may choose to offer other safety apps that use V2V technology other than or beyond these two and may offer those technologies or IMA and LTA in a time frame different than what is assumed here. In addition, manufacturers may also offer various other technologies that use DSRC, such as vehicle-to-infrastructure (V2I) or vehicle-to-pedestrian (V2P) technologies. These other technologies may offer benefits and accrue costs different than what we have assumed and which may accrue on a different time line. However, in order to provide an estimate of the potential quantified safety benefits of a V2V mandate, the agency assumed the installation of IMA and LTA in the time frame discussed above.

Maximum Annual Benefits

The maximum annual benefits represent the crashes, fatalities, injuries, and property damage vehicles (PDOVs) that can be reduced annually after the full adoption of DSRC and the two safety apps.[8] Undiscounted, at full V2V adoption, the proposed rule would

- Prevent 439,000 to 615,000 crashes (equivalent to 13 to 18 percent of multiple light-vehicle crashes)
- Save 987 to 1,366 lives
- Reduce 305,000 to 418,000 MAIS 1-5 injuries,[9] and
- Eliminate damage to 537,000 to 746,000 property damage only vehicles (PDOVs).

Annual Benefits

The annual benefits represent the benefits that would be accrued collectively by all V2V-vehicles in a calendar year. Table E-3 summarizes the undiscounted annual benefits from 2021 to 2060 for every 5 year period. The table shows that the proposed rule would not have benefit for Year 1 due to the 0 percent app adoption for new vehicles in that year. At Year 5 (2025), the proposed rule would prevent 10,094 to 13,763 crashes. In eliminating these crashes, the proposed rule would save 23 to 31 lives and reduce 6,946 to 9,197 MAIS 1-5 injuries. In addition, the proposed rule would avoid damage to 12,496 to 16,949 vehicles that in baseline crashes had no injury, but only resulted in property damage (i.e., PDOVs).

At Year 10, the proposed rule would prevent 107,120 to 147,615 crashes, save 244 to 332 lives, and reduce 73,983 to 99,254 MAIS 1-5 injuries. In Year 10, the benefit is more than 10 times of that at Year 5. At Year 20, the proposal would prevent 349,914 to 487,561 crashes, save 789 to 1,089 lives, and reduce 242,589 to 329,909 MAIS 1-5 injuries. The benefit level in in Year 20 is about 80 percent of the maximum benefits.

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[8] Would occur 43 years after the first implementation

[9] MAIS (Maximum Abbreviated Injury Scale) represents the maximum injury severity of an occupant at an Abbreviated Injury Scale (AIS) level. AIS ranks individual injuries by body region on a scale of 1 to 6: 1=minor, 2=moderate, 3=serious, 4=severe, 5=critical, and 6=maximum (untreatable).

Table E-3
Summary of Annual Benefits of the Proposed Rule
(**Undiscounted**)

	Calendar	Crashes		Fatalities		MAIS 1-5 Injuries		PDOVs	
Year	Year	Low	High	Low	High	Low	High	Low	High
1	2021	0	0	0	0	0	0	0	0
5	2025	10,094	13,763	23	31	6,946	9,197	12,496	16,949
10	2030	107,120	147,615	244	332	73,983	99,254	131,946	180,693
15	2035	241,740	335,287	547	751	167,329	226,278	296,835	408,920
20	2040	349,914	487,561	789	1,087	242,589	329,909	428,697	593,093
25	2045	401,894	561,737	904	1,249	278,926	380,771	491,628	682,127
30	2050	424,901	594,569	955	1,321	295,009	403,284	519,483	721,535
35	2055	435,932	610,326	980	1,355	302,723	414,094	532,831	740,437
40	2060	439,138	615,028	987	1,365	304,986	417,366	536,657	745,996

MAIS: Maximum Abbreviated Injury Scale; PDOVs: property damage only vehicles

Figure E-1 is the graphic presentation of the annual crash benefits. This is used as an example to depict the annual benefit pattern by years. The two curves represent the low and high bounds of the crash benefits, respectively. Annual benefits for fatalities, MAIS 1-5 injuries, and PDOVs follow the same patterns of these two curves.

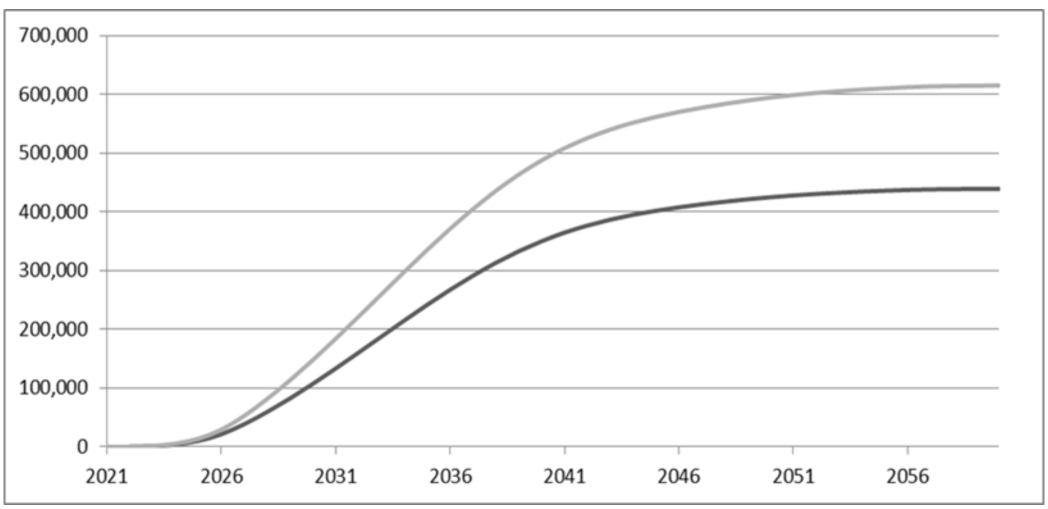

Figure E-1
Range of Annual Crash Benefits from 2021 to 2060

Lifetime Benefits for a MY of Vehicles

The lifetime benefits for a MY of vehicles (also MY Benefits) represent the total benefits that would be accrued through the lifetime of a MY of vehicles. These benefits were discounted at 3 percent and 7 percent to represent their present value. For example, passenger cars (PCs) have a lifespan of 30 years and the MY 2030 PCs will be on the road from 2030 to 2059. During that time, the MY 2030 vehicles will communicate with an increasing percentage of later model years of vehicles that have V2V. Each of those year, the MY 2030 vehicles are expected to accrue some benefits. These annual benefits are discounted back to the year the vehicle was purchased. The estimated lifetime benefits for MY 2030 vehicles thus are the accumulation of these discounted benefits over their lifetime. Tables E-4 presents the discounted MY benefits from MY 2021 to MY 2050 vehicles for every five MYs. As shown, the first MY vehicles (i.e., MY 2021) would not accrue benefits due to the adoption scenario used in the PRIA. At a 3 percent discount rate, the 5th applicable MY vehicles (MY 2025) would prevent 20,094 to 82,481 crashes, save 46 to 186 lives, and reduce 13,847 to 55,459 MAIS 1-5 injuries. At this discount rate, the MY 2025 would also eliminate 24,828 to 100,913 PDOVs. The 30th MY vehicles (MY 2050) would prevent 261,241 to 453,138 crashes, save 587 to 1,006 lives, reduce 181,408 to 307,409 injuries, and eliminate 319,322 to 549,803 PDOVs.

At a 7 percent discount rate, MY 2025 vehicles would prevent 18,321 to 65,517 crashes, save 42 to 145 lives, reduce 12,623 to 43,361 MAIS 1-5 injuries and eliminate 22,643 to 79,010 PDOVs. The MY 2050 vehicles would prevent 214,216 to 396,388 crashes, save 481 to 880 lives, reduce 148,751 to 268,906 MAIS 1-5 injuries, and eliminate 261,848 to 480,956 PDOVs.

Table E-4
Summary of the MY Benefits
@3 Percent Discount

Year	Model Year	Crashes		Fatalities		MAIS 1-5 Injuries		PDOVs	
		Low	High	Low	High	Low	High	Low	High
1	2021	0	0	0	0	0	0	0	0
5	2025	20,094	82,461	46	186	13,847	55,459	24,828	100,913
10	2030	175,685	276,526	398	619	121,501	186,614	215,991	337,269
15	2035	234,712	362,101	530	809	162,695	244,762	287,627	440,931
20	2040	254,958	425,875	574	948	176,909	288,466	311,982	517,525
25	2045	255,409	438,253	574	974	177,320	297,187	312,289	531,965
30	2050	261,241	453,138	587	1,006	181,408	307,409	319,322	549,803

@7 Percent Discount

Year	Model Year	Crashes		Fatalities		MAIS 1-5 Injuries		PDOVs	
		Low	High	Low	High	Low	High	Low	High
1	2021	0	0	0	0	0	0	0	0
5	2025	18,321	64,517	42	145	12,623	43,361	22,643	79,010
10	2030	154,035	222,006	349	497	106,513	149,758	189,411	270,886
15	2035	191,219	316,898	432	708	132,525	214,173	234,382	385,947
20	2040	208,845	372,995	470	831	144,901	252,625	255,587	453,305
25	2045	209,421	383,630	471	853	145,388	260,137	256,071	465,677
30	2050	214,216	396,388	481	880	148,751	268,906	261,848	480,956

MAIS: Maximum Abbreviated Injury Scale; PDOVs: property damage only vehicles

Figure E-2 uses MY crash benefits at a 3 percent discount rate as an example to depict the MY benefit patterns. As shown, the two curves represent the low and high bounds of the MY crash benefits, respectively. The slightly decrease between 2041 and 2043 MYs is due to the decrease vehicle sale projection for these MY vehicles.[10] MY benefits for fatalities, MAIS 1-5 injuries, and PDOVs follow the same patterns. Furthermore, the MY benefits at a 7 percent discount rate also follow the same patterns.

[10] Based on the historic vehicle sales from 1974 to 2013, in certain years the sales were down from the previous year due to economic outlook or other reasons. This influenced the projected vehicle sales pattern.

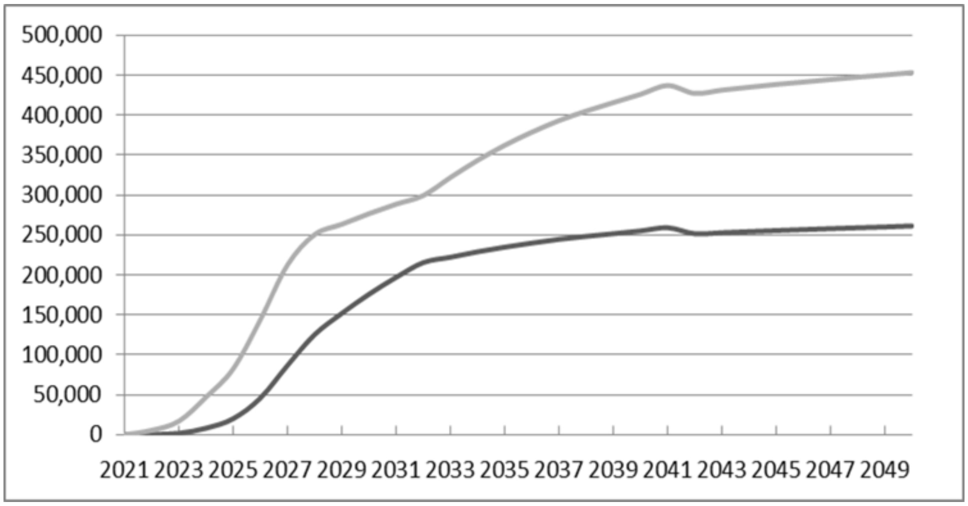

Figure E-2
Range of MY Crash Benefits for MY 2021 to MY 2050 Vehicles

Note that the range of benefits for each MYs' vehicles is due to the use of a range of effectiveness rates and the two MY benefit estimating approaches. The two benefit approaches, labeled as "free-rider" and "no free-rider" approaches, deployed a different treatment on the distribution of benefits from crashes involving different MY vehicles.

Monetized Annual Benefits

The monetized benefits were represented by the comprehensive value of the benefits. Comprehensive values (or costs) included the savings from medical care, emergency services, insurance administration, workplace costs, legal costs, congestion, property damage, lost productivity and the nontangible value of quality of life (QALYs). Congestion costs included travel delay, added fuel usage, and adverse environmental impacts cost.[11] All monetized values

[11] Environment impacts included the estimated reduction of greenhouse gas and pollutant emissions due to vehicle delay hours and added fuel consumption that resulted from congestion caused by crashes.

are in 2014 dollars. The comprehensive cost for a fatality is $9.7 million[12] in 2014 dollars which is based on the value of statistical life (VSL) of $9.4 million.[13]

Monetized Maximum Annual Benefits

The proposed rule would save a maximum of $54.7 to $74.0 billion annually after the full adoption of DSRC radios and the two safety apps. Of these amounts, $7.7 to $10.6 billion are savings from reducing crash related congestion and vehicle property damage. Generally, the congestion savings comprised about 27 percent of the congestion and property damage savings.

Monetized Annual Benefits

Table E-5 shows the monetized annual benefits corresponding to the annual benefits estimated previously. As shown, the proposed rule would save $1.3 to $1.6 billion in 2025. The savings are progressively increased to $54.7 to $73.9 billion by 2060. The annual congestion and property damage savings, which are a subset of total monetized benefits, are estimated to be $0.18 to $0.24 billion in 2025 and to increase to $7.7 to $10.6 billion in 2060. The increase patterns for monetized benefits follow those depicted in Figure E-1.

[12] Derived from the unit costs published in the report: Blincoe, L. J., Miller, T. R., Zaloshnja, E., & Lawrence, B. A. (2015, May). The economic and societal impact of motor vehicle crashes, 2010. (Revised) (Report No. DOT HS 812 013). Washington, DC: National Highway Traffic Safety Administration

[13] For more information, please see a 2015 Office of the Secretary memorandum on the "Guidance on Treatment of the Economic Value of a Statistical Life in U.S. Department of Transportation Analyses." http://www.dot.gov/regulations/economic-values-used-in-analysis.

Table E-5
Monetized Annual Benefits
(2014 $ in **Millions**)

Year	Calendar Year	Total Monetized Benefits		Property Damage and Congestion	
		Low	High	Low	High
1	2021	$0	$0	$0	$0
5	2025	$1,256	$1,644	$176	$237
10	2030	$13,336	$17,678	$1,870	$2,546
15	2035	$30,098	$40,212	$4,222	$5,787
20	2040	$43,570	$58,537	$6,113	$8,420
25	2045	$50,045	$67,490	$7,023	$9,705
30	2050	$52,911	$71,453	$7,425	$10,274
35	2055	$54,285	$73,356	$7,618	$10,547
40	2060	$54,685	$73,926	$7,675	$10,629

Monetized MY Benefits

Table E-6 shows the monetized MY benefits. At a 3 percent discount rate, the MY 2025 vehicles would save a total of $2.5 to $9.9 billion through their 37-year lifespans. Of these savings, $0.4 to $1.4 billion are derived from property damage and congestion savings. In comparison, the MY 2050 vehicles would save $32.5 to $54.5 billion, of which $4.6 to $7.8 billion are property damage and congestion savings. The MY 2050 benefits can be considered as the benefits at full technology penetration for all on-road light vehicles.

At a 7 percent discount rate, the MY 2025 vehicles would save $2.3 to $7.7 billion. Of these savings, $0.3 to $1.1 billion are from property damage and congestion savings. The MY 2050 vehicles would save a total of $26.7 to $47.6 billion, of which $3.7 to $6.9 billion are property damage and congestion savings. The increase patterns for monetized MY benefits follow those depicted in Figure E-2.

Table E-6
Monetized MY Benefits (2014 $ in Millions)
@3 Percent Discount

Year	Model Year	Total Monetized Benefits		Property Damage and Congestion	
		Low	High	Low	High
1	2021	$0	$0	$0	$0
5	2025	$2,501	$9,876	$351	$1,422
10	2030	$21,873	$33,164	$3,068	$4,773
15	2035	$29,225	$43,456	$4,101	$6,252
20	2040	$31,748	$51,152	$4,455	$7,357
25	2045	$31,805	$52,663	$4,463	$7,572
30	2050	$32,532	$54,460	$4,565	$7,830

@7 Percent Discount

Year	Model Year	Total Monetized Benefits		Property Damage and Congestion	
		Low	High	Low	High
1	2021	$0	$0	$0	$0
5	2025	$2,281	$7,725	$320	$1,112
10	2030	$19,177	$26,621	$2,690	$3,831
15	2035	$23,810	$38,029	$3,341	$5,471
20	2040	$26,006	$44,799	$3,649	$6,443
25	2045	$26,078	$46,098	$3,660	$6,629
30	2050	$26,676	$47,640	$3,744	$6,850

Annual Costs

Total Annual Costs

The annual costs represent the total annual capital investment and fuel economy impact from all V2V-equipped vehicles per year. The costs comprise four major categories: (1) vehicle technology (i.e., DSRC radios and app), (2) SCMS, (3) equipment and communication network in support of vehicles-to-SCMS communication (i.e., Communication), and (4) fuel economy impact due to the increased weight from the in-vehicle equipment in (1) and (3).

Table E-7 presents the total annual costs and annual cost per vehicle. The total annual costs would range from $2.2 billion (lower bound for 2021 when 50 percent of the fleet must comply) to $5.0 billion (not shown, upper bound for 2024). The annual cost per vehicle would range from $135 to $301 (lower bound for 2021 and upper bound for 2024). The lower and upper bounds represent the two technology implementation approaches (one-radio and two-radios) that can be used to meet the proposed rule including the security and privacy specifications.

Table E-7
Total Annual Costs and Annual Cost Per Vehicle
(2014 $)

Year	Calendar Year	Annual Costs (**Million** $)		Annual Cost per Vehicle	
		Low	High	Low	High
1	2021	$2,192	$2,864	$135.38	$176.89
5	2025	$3,701	$4,803	$222.02	$288.13
10	2030	$3,649	$4,692	$210.94	$271.22
15	2035	$3,717	$4,757	$206.52	$264.26
20	2040	$3,831	$4,844	$203.01	$256.71
25	2045	$3,796	$4,764	$201.14	$252.49
30	2050	$3,858	$4,818	$198.97	$248.50
35	2055	$3,832	$4,766	$197.65	$245.80
40	2060	$3,804	$4,717	$196.20	$243.27

Figure E-3 depicts the annual costs from 2021 to 2060. The upper curve represents the high cost estimates that correspond to the two-radio approach (i.e., pairing with the DSRC communication). The lower curve represents the low cost estimates that correspond to the one-radio approach.

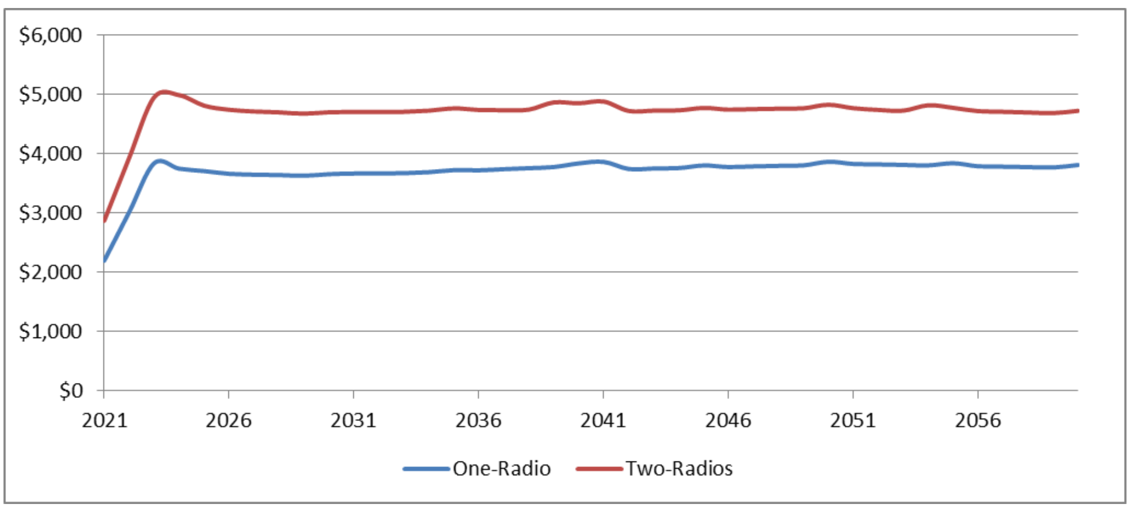

Figure E-3
Annual Costs of the Proposed Rule from 2021 to 2060

Note that these costs have already been adjusted for the learning effect[14] - the cost savings that manufacturers will realize due to their progressive experience with manufacturing the product.

[14] See the Cost chapter for additional discussion on the learning effect.

The cost per vehicle is the average cost per new vehicle instead of per affected vehicle that would be required by the technology during the phase-in period. This normalized per vehicle cost allows a straightforward comparison between various technology approaches and regulatory alternatives. The vehicle technology cost was initially estimated to range from $249 to $351 per affected vehicle including the component costs for DSRC radios, DSRC antenna, GPS, hardware security module, two apps, and malfunction telltale as well as the installation labor costs. The vehicle component unit costs were based on the supplier's confidential response to the agency's request for cost information. Table E-8 summarizes the initial technology costs.

Table E-8

Summary of V2V Technology Costs

Cost Items	One Radio	Two-Radios
Components*	$245.79	$347.18
Installation	$17.74	$17.74
Subtotal	$263.53	$364.92
Minus Current GPS Installation**	$14.35	$14.35
Total	$249.18	$350.57

* including the cost of apps

** takes into account that 50 percent of vehicles already have GPS

Total Annual Costs by Cost Category

Table E-9 lists the total annual costs separately for the four cost categories– low and high total costs and lower and high vehicle unit costs. As shown, the majority of costs came from vehicle technology costs. The annual vehicle technology costs ranged from $2.0 to $4.9 billion (in 2023, not shown) and the per vehicle cost ranged from $124 to $298.

The SCMS costs included the costs for the establishment, operation, and maintenance of the system that covered the expenditure on human resources, equipment, facilities, energy, etc. The total annual SCMS costs would range from $39 to $161 million. This is equivalent to $2 to $8 per new vehicle annually.

The communication costs included the costs for equipment and communication network that are needed in support of the vehicle-to-SCMS communication. The annual communication costs would range up to $494 million. The communication cost per vehicle would be up to $26 per vehicle.

The fuel economy impact was based on the added weight of 3.38 pounds for the two-radio technology approach and 3.21 pounds for the one-radio approach. Due to the insignificant weight difference between these two approaches, the estimated fuel economy impacts are identical for these approaches when factoring rounding errors. Therefore, the fuel economy impact as shown applies to both approaches. The annual fuel economy impact would range from $3 to 135 million. This equates to up to $7 per vehicle.

Table E-9
Total Annual Costs by Cost Category
(2014 $)

Vehicle Technology Costs

Year	Calendar Year	Total Costs (Million $)		Cost Per Vehicle	
		Low	High	Low	High
1	2021	$2,001	$2,822	$123.59	$174.29
5	2025	$3,297	$4,646	$197.79	$278.68
10	2030	$3,160	$4,447	$182.63	$257.06
15	2035	$3,135	$4,413	$174.17	$245.17
20	2040	$3,178	$4,473	$168.39	$237.03
25	2045	$3,096	$4,359	$164.09	$230.98
30	2050	$3,115	$4,385	$160.67	$226.16
35	2055	$3,061	$4,308	$157.85	$222.19
40	2060	$3,015	$4,243	$155.47	$218.85

SCMS Costs*

Year	Calendar Year	Total Costs (Million $)	Cost Per Vehicle
1	2021	$39	$2.42
5	2025	$47	$2.80
10	2030	$59	$3.44
15	2035	$86	$4.77
20	2040	$100	$5.29
25	2045	$122	$6.48
30	2050	$138	$7.13
35	2055	$153	$7.89
40	2060	$161	$8.29

*does not impacted by technology approaches

Communication

Year	Calendar Year	Total Costs (Million $)		Cost Per Vehicle	
		Low	High	Low	High
1	2021	$0	$1,486	$0.00	$9.18
5	2025	$85	$3,324	$5.15	$19.94
10	2030	$135	$3,799	$7.81	$21.96
15	2035	$185	$4,229	$10.24	$23.49
20	2040	$178	$4,597	$9.42	$24.36
25	2045	$178	$4,709	$9.42	$24.96
30	2050	$178	$4,873	$9.16	$25.13
35	2055	$178	$4,917	$9.16	$25.36
40	2060	$178	$4,939	$9.16	$25.47

Fuel Economy Impact*

Year	Calendar Year	Fuel Consumption (Million Gallons)	Fuel Costs (Million $)	Cost Per Vehicle
1	2021	1.10	$3.08	$0.19
5	2025	8.34	$24.94	$1.50
10	2030	16.01	$50.27	$2.91
15	2035	21.76	$73.55	$4.09
20	2040	25.64	$93.84	$4.97
25	2045	27.83	$105.75	$5.60
30	2050	29.21	$117.13	$6.04
35	2055	30.10	$127.02	$6.55
40	2060	30.51	$135.16	$6.97

* Due to insignificant weight difference between the one-radio and two-radio technology implementation approaches, these estimates are used for both approaches

Model Year Costs

The primary difference between the annual and MY costs is the fuel economy impact. The PRIA assumes that vehicle technology, SCMS, and communication costs would be paid by vehicle owners when their vehicles were purchased. Thus, these three costs are identical between the annual and MY costs. In annual costs, the fuel economy impact measures the additional fuel costs for all V2V-equipped MY vehicles in a specific calendar year. For estimating the MY costs, the fuel economy impact measures the incremental lifetime fuel impact for a specific MY vehicles and were discounted at a 3 and 7 percent rate to reflect their present value at time of purchase. Note that the fuel economy impact accounts for the fuel efficiency improvement specified in the CAFÉ rule for MY 2021 to 2025 vehicles.

Table E-10 shows the MY costs. At a 3 percent discount rate, the MY costs would range from $2.22 (lower bound for MY 2021 when 50 percent of the fleet are required to comply) to $5.03 billion (upper bound for MY 2024, not shown). The cost per vehicle would range from $137.21 to $304.06 (MY 2024, not shown). The lower bound of the costs represents the MY costs for the one-radio approach and the higher bound represents the cost for the two-radio approach.

At a 7 percent discount rate, the MY costs would range from $2.21 (lower bound for MY 2021) to $5.01 billion (upper bound for MY 2024, not shown). The MY cost per vehicle would range from $136.73 to $303.14. As discussed earlier, the difference between the annual and MY costs is the fuel economy impact which comprises a very small portion of the overall costs. Therefore, the cost pattern for MY costs is similar to that depicted in Figure E-3 and is not provided here.

Table E-10
Total MY Costs and Cost Per Vehicle

@3 Percent Discount

Year	Model Year	Total MY Costs (Million $)		MY Cost per Vehicle	
		Low	High	Low	High
1	2021	$2,221	$2,894	$137.21	$178.72
5	2025	$3,740	$4,842	$224.36	$290.46
10	2030	$3,671	$4,714	$212.21	$272.49
15	2035	$3,726	$4,765	$206.98	$264.72
20	2040	$3,829	$4,842	$202.92	$256.61
25	2045	$3,787	$4,756	$200.68	$252.03
30	2050	$3,846	$4,806	$198.33	$247.86

@7 Percent Discount

Year	Calendar Year	Total MY Costs (Million $)		MY Cost per Vehicle	
		Low	High	Low	High
1	2021	$2,214	$2,886	$136.73	$178.25
5	2025	$3,725	$4,827	$223.45	$289.56
10	2030	$3,654	$4,697	$211.22	$271.51
15	2035	$3,706	$4,746	$205.92	$263.66
20	2040	$3,808	$4,821	$201.78	$255.47
25	2045	$3,764	$4,733	$199.49	$250.83
30	2050	$3,821	$4,782	$197.09	$246.61

Net Benefits

Net Benefits are the difference between the monetized benefits and the costs. Because both benefits and costs have annual and MY measures, the net benefits are also presented in these two measures, i.e., annual net benefits and MY net benefits. Similar to the cost and benefit estimates, the annual net benefits were not discounted and were for 40 years and MY net benefits were discounted and for 30 MY vehicles. Undiscounted, the annual net benefits would be up to $70.1 billion from 2021 to 2060. These annual net benefits were discounted and were used in the breakeven analysis to determine the year that the proposed rule will recoup all the investment up to that year through the benefits.

For MY net benefits, at a 7 discount rate, the benefits would be up to $50.6 billion. At a 7 discount rate, the benefits would be up to $43.8 billion. The MY net benefits were used in the net-benefit analysis to determine the MY of vehicles that the proposed rule will start to accrue positive net benefits.

Breakeven Analysis

Breakeven analysis determines the year that total discounted cumulative monetized annual benefits will be equal to the total discounted cumulative annual costs. Table E-11 shows the breakeven year by discount rates. The proposed rule would breakeven between 2029 and 2032.

Table E-11
Breakeven Year of the Proposed Rule

Discount Rate	Year
At 3 Percent	2029 to 2031
At 7 Percent	2030 to 2032

Cost-Effectiveness Analysis

The cost-effectiveness analysis determines the MY vehicles that would be cost-effective. A vehicle MY is cost-effective if its net MY cost per equivalent life saved is no greater than the

$9.7 million comprehensive cost of a fatality.[15] The net MY cost as defined in the PRIA is the total MY cost minus the MY property damage and congestion savings. To derive the cost per equivalent life saved for a MY vehicles, the MY injury and PDOV benefits were translated into equivalent lives saved according to their relative comprehensive costs to that of a fatality. The earliest MY vehicles would become cost-effective is between MY 2024 and 2026 vehicles as shown in Table E-12.

Table E-12
Summary of the MY That Would Be Cost-Effective

Discount Rate	MY
At 3 Percent	2024 to 2026
At 7 Percent	2024 to 2026

Net-Benefit Analysis

The net-benefit analysis determines the MY vehicles that would accrue positive net MY benefits. The net MY benefit is the difference between the monetized MY benefits and MY costs. Table E-13 shows that the earliest MY vehicles would accrue a positive net benefit is also between MY 2024 and 2026.

Table E-13
Summary of the MY That Would Have Net Benefits

Discount Rate	MY
At 3 Percent	2024 to 2026
At 7 Percent	2024 to 2026

Regulatory Alternatives

The agency considered two regulatory alternatives to the proposed rule: (1) mandating both V2V communication capability and safety apps (Alternative 1) and (2) an “If-Equipped” alternative

[15] Revised to 2014 dollar from the unit costs published in this report, Blincoe, L. J., Miller, T. R., Zaloshnja, E., & Lawrence, B. A. (2015, May). The economic and societal impact of motor vehicle crashes, 2010. (Revised) (Report No. DOT HS 812 013). Washington, DC: National Highway Traffic
Safety Administration

(Alternative 2), which allows the manufacturers voluntarily to equip their vehicles with the V2V technology only if it would comply with specified performance requirements. For installation of the communication system, Alternative 1 would require the same three-year phase-in schedule (50%-75%-100%) as would the proposed rule. For app adoption, Alternative 1 would require a four-year phase in, a one year delay: 0%-50%-75%-100%.

For Alternative 2, the "If-Equipped" alternative[16], the agency expects that the implementation of V2V communication (assumed to be DSRC) and apps would be both slower for this voluntary standard than for a mandatory alternative and would most likely to stay flat thereafter, never reaching all or even a significant percentage of the fleet. This is because the cost of installing V2V on any particular vehicle is not dependent on adoption by others, while the benefits are. This cloud of uncertainty surrounding the possible benefits and the disparity on benefits between the early and late adopters is expected to exacerbate the adoption of V2V absent a mandate. With these considerations, the agency assumes that a 5 percent DSRC adoption for MY 2021 vehicles and a 5 percent increase for the subsequent years until the rate reaches 25 percent for MY 2025. The rate would stay at 25 percent onward. This assumption is broadly based upon adoption rates of other advanced technologies in the absence of a mandate. It is also based on our belief that under a voluntary scenario, any installation of DSRC would likely be confined to higher priced vehicles. The 25 percent represents the approximate market share of all light vehicles with a base price over $30,000.[17] For app adoption, Alternative 2 would have the same implementation schedule as would the proposed rule since apps would be voluntary for both regulatory options. Table E-14 summarizes the DSRC and app adoptions rates for the proposed rule and these two alternatives. Simply put, the major difference between Alternative 1 and the proposed rule is the app adoption and between Alternative 2 and the proposed rule is the DSRC adoption.

[16] The agency believes that V2V would not occur in the absence of any government action and has, therefore, not estimated a "no action" alternative. We request comment on this assumption.

[17] 2016 Ward's Automotive Yearbook

Table E-14
V2V Technology Adoption Rates in Percent

DSRC Adoption Rates

Regulation Alternatives	Model Year							
	2021	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028+**
The Proposed Rule Mandating DSRC	50	75	100	100	100	100	100	100
Alternative 1 Mandating DSRC and Apps	50	75	100	100	100	100	100	100
Alternative 2 If-Equipped	5	10	15	20	25	25	25	25

App Adoption Rates*

Regulation Alternatives	Model Year							
	2021	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028+**
The Proposed Rule Mandating DSRC	0	5	10	25	40	65	90	100
Alternative 1 Mandating DSRC and Apps	50	75	100	100	100	100	100	100
Alternative 2 If-Equipped	0	5	10	15	20	25	25	25

*as percent of DSRC-equipped vehicles

Because of the aggressive app adoption, Alternative 1 would be expected to accrue more annual benefits than the proposed rule before the entire on-road fleet has been equipped with V2V (i.e., reaching the maximum benefits). Alternative 1 would also reach the same maximum annual benefits as the proposed rule, but would do so four years earlier. This alternative would achieve these benefits without significant cost increase, since the incremental cost of adding two apps over the DSRC radios is very small (less than 0.1 percent of the vehicle technology cost). The annual costs of this alternative would range from $2.2 to $5.0 billion.

Alternative 2 would accrue up to 6 percent of the maximum annual benefits of the proposed rule due to lower DSRC and app adoption rates. This alternative also has relatively lower annual costs than that of the proposed rule, since far fewer vehicles would be installed with DSRC. The annual cost of this alternative would range from $254 million to $1.3 billion, with an average annual cost about 26 percent of the cost of the proposed rule.

Table E-15 summaries the cost-benefit measures (i.e., breakeven, cost-effectiveness, and net-benefits) for these two alternatives. For an easy comparison, Table E-15 also includes the cost-benefit measures for the proposed rule. As shown, Alternative 1 would breakeven between 2027 and 2030 (combining 3 and 7 percent discount rates), two years ahead of the proposed rule. The first MY vehicles that would be cost-effective and that would accrue positive net benefits is expected to be between MY 2024 and MY 2026, also two years earlier than the proposed rule. In contrast, Alternative 2 would breakeven between 2037 and 2055, eight to twenty-three years behind the proposed rule. The first MY vehicles that would be cost-effective under Alternative 2 is expected to be between MY 2026 and MY 2031, two to five years later than the proposed rule. The first MY vehicles that would accrue positive net benefits is between MY 2026 and MY 2033, two to seven years later than the proposed rule.

Table E-15
Summary of Cost-Benefit Measures

At 3 Percent Discount

Cost-Benefit Measures	**Alternative 1** Mandating DSRC Radios and Apps	**The Proposed Rule** Mandating DSRC Only	**Alternative 2** If-Equipped
Breakeven (CY)	2027 to 2029	2029 to 2031	2037 to 2045
Cost-Effectiveness (MY)	2022 to 2024	2024 to 2026	2026 to 2030
Positive Net Benefits (MY)	2022 to 2024	2024 to 2026	2026 to 2031

At 7 Percent Discount

Cost-Benefit Measures	**Alternative 1** Mandating DSRC Radios and Apps	**The Proposed Rule** Mandating DSRC Only	**Alternative 2** If-Equipped
Breakeven (CY)	2027 to 2030	2030 to 2032	2039 to 2055
Cost-Effectiveness (MY)	2022 to 2024	2024 to 2026	2027 to 2031
Positive Net Benefits (MY)	2022 to 2024	2024 to 2026	2027 to 2033

CY: calendar year, MY: model year of vehicles

Although mandating V2V communication technology and V2V-based apps can guarantee the significant safety benefits that would be realized every year, the agency is not ready to mandate the two safety apps with this NPRM. The agency believes that additional research is needed. Specifically, the research for establishing test procedures and performance criteria of the apps is critical to an effective app in reducing crashes and meeting the requirements of the Motor Vehicle Safety Act. Without the crucial research, the agency is concerned that mandating apps might lead to unintended consequences and has negative effects on the development and deployment of V2V-based apps. Further, the proposed rule mandating only the V2V communication technology allows for the implementation of interoperable V2V communication devices. Mandating V2V provides the hardware platform for safety app development. This removes the biggest obstacle from the deployment of V2V-based apps and app development is a marginal cost. Thus, the agency believes a proposed mandate of V2V communication without a mandate for apps will encourage a free-market approach for the development and deployment of safety applications, which the agency believes will innovate. The low cost of implementation of apps gives us confidence that manufacturers could realistically undertake to develop such applications and begin deploying them in the field once DSRC is mandated. Therefore, the agency decided not to select Alternative 1.

The agency also decided not to select Alternative 2. Based on the estimated costs of V2V communication and the network-reliant nature of the V2V communication, the agency believes that Alternative 2 is unlikely to lead to meaningful deployment of V2V. Furthermore, a 2014 study from the Highway Loss Data Institute found that Government mandates could speed up the market penetration rate of partially automatic crash avoidance technologies by up to 15 years.[18] Therefore, Alterative 2 would delay potentially for a significant period of time and result in greater uncertainty on the anticipated benefits and wider disparity on benefits between early and late adopters than would the proposed rule. For these reasons, Alternative 2 was not selected.

While we are proposing a V2V communications mandate, we also seek further comment on the costs and benefits of an "if-equipped" option, particularly considering the substantial safety

[18] Highway Loss Data Institute, 2014, Predicted Availability of Safety Features on Registered Vehicles Bulletin Vol. 31, No. 15, Insurance Institute for Highway Safety, Arlington, VA.

benefits and potential social costs of a mandate. How the market would deploy a technology under this option and what are the associated challenges? Do commenters believe an if-equipped option would be a preferable approach, and if so, why? What costs and/or benefits should we consider relative to an if-equipped approach, and how do those costs and benefits compare to our analysis of the costs and benefits of a mandate? Furthermore, we seek additional comment on how an if-equipped option may potentially delay or lead to uncertainty in V2V technology development. In addition, we are interested in what benefits may accrue from a more gradual, market-based approach to a technology that has never before been widely deployed? What affect would such an approach have on the ability to iterate and test potential V2V technology solutions, potentially leading to a less costly and/or more robust and secure deployment? Could an if-equipped approach allow for improved consumer choice and better privacy protections? If we were to take such an approach, how might it affect the FCC's consideration of matters related to spectrum utilization, as discussed in more detail later in this document? We also seek examples and information related to other network-reliant technologies which successfully evolved in the absence of a government mandate, as well as examples of similar network-reliant technologies that were mandated, either successfully or not.

Non-Quantified Impacts

The PRIA also discusses the potential benefits and costs of the proposed rule that cannot be quantified at this time. The non-quantified benefits of the proposed rule can come from several sources: (1) the effects of enhancing vehicle-resident safety systems, (2) the incremental benefits over the current vehicle-resident safety systems, (3) the potential impact of the next generation V2V apps that would actively assist drivers to avoid crashes rather than simply issuing warnings, (4) the impact of enabling wide range deployment of V2P and V2I apps, and (5) the effects of assisting development of full automation. The agency believes that fusion of V2V and vehicle-resident technologies will be crucial to the potential for truly self-driving vehicles. V2V would accomplish this by connecting vehicles not only with other vehicles, but also with roadway infrastructure (V2I), and even with pedestrians (V2P). These technologies (collectively referred to as "V2X technology") can augment sensors to enhance both range and resolution and provide more data for safety systems. Ultimately V2X technology would provide a vehicle with the highest level of awareness of its surroundings and allow the automation systems to react far quicker to situations than they would with sensors. Therefore, V2V is essential to full automation by allowing vehicles to monitor roadway, traffic, and driving conditions and timely perform safety-critical functions. The agency does not quantify these impacts primarily due to lack of data (e.g., effectiveness of the apps, incremental effective rate of the V2V apps over the vehicle-resident systems, etc.) that can be used to discern these benefits. The Benefit chapter discussed these benefits in detail.

The agency identified four non-quantified costs. These include (1) health costs due to a potential increase in electromagnetic hypersensitivity (EHS, i.e., human radiation exposure to wireless communications)[19], (2) perceived loss of privacy, (3) opportunity costs of using the spectrum for something else, and (4) possibly an increase in litigation costs. The agency does not quantify these costs due to various reasons. For EHS, the agency has not uncovered any concrete relationship between V2V electromagnetic radiation and EHS at this time. The Food and Drug Administration also stated that most studies conducted to date show no connection between certain health problems and the exposure to radio frequency fields of cell phone use. For perceived privacy loss, the agency did not quantify it because the perception of and the level of sensitivity to privacy depends on the type of information collected and how it would be used. There are no standardized economic values that can be associated with different levels of sensitivity. For spectrum use, at this moment Channel 172 is designated to be exclusively used for V2V DSRC communication for public and non-public safety use. Other commercial usages are not allowed. The Federal Communications Commission (FCC) is the Federal agency that has the authority to grant authorize non-federal spectrum use. The FCC is considering whether to allow "Unlicensed National Information Infrastructure" devices to operate in the same area of

[19] Many individual citizens commented about the effects of EHS. The Agency has not uncovered any concrete relationship between V2V electromagnetic radiations to EHS at this moment. The Food and Drug Administration also stated that most studies conducted to date show no connection between certain health problems and exposure to radio frequency fields of cell phone use. Nevertheless, the Agency will continue to monitor new developments by experts in this field.

the wireless spectrum range as V2V.[20] In December 2015 and January 2016, the DOT, FCC, and the Department of Commerce sent joint letters to members of the U.S. Senate Committee on Commerce, Science and Transportation delineating a collaborative multi-phased approach that will be used to provide real world data on the performance of unlicensed devices that are designed to avoid interfering with DSRC operations in the 5.850-5.925 GHz band. The agency also is planning research on the impact of spectrum sharing. The proposed rule, and the V2V research to date, is based on the spectrum band plan and use specifications that were established by the FCC. While a possible methodology for quantifying the opportunity cost of spectrum is discussed below in Chapter VII, Section F, due to uncertainty, the PRIA does not include this opportunity costs. However, the opportunity cost associated with spectrum will be included in the final cost benefit analysis when the agency publishes the final regulatory impact analysis. As for a possibly increase in litigation costs, the agency believes that the V2V technology is expected to avoid up 615,000 crashes and thus would reduce the overall burden imposed on legal systems.

Sensitivity and Uncertainty Analyses

The PRIA presents sensitivity and uncertainty analyses that address the uncertainty surrounding the benefits and costs of the proposed rule.

Sensitivity Analysis

The sensitivity analysis examines the impact of using alternative $5.3 million and $13.2 million VSLs on the cost-benefit measures.[21] Using these VSLs, the monetized benefits would be 65 percent to 132 percent of the primary estimates as shown above (i.e., using $9.4 VSL). The sensitivity analysis on VSLs shows that the high and low VSLs affect mostly the breakeven analysis. The breakeven years can be either one year early or three year later than the primary

[20] Unlicensed National Information Infrastructure (UNII) devices provide short-range, high-speed, unlicensed wireless connections for, among other applications, Wi-Fi-enabled radio local area networks, cordless telephones, and fixed outdoor broadband transceivers used by wireless Internet service providers.

[21] Revised from the $5.3 million and $13.2 VSL specified in the DOT 2015 Guidance on VSL in 2013 dollars to 2014 dollars.

estimated years. However, the VSL range has almost no impact on the cost-effectiveness and net-benefit analyses.[22] Table E-16 summarizes the cost-benefit measures for the two alternative VSLs by two discount rates.

Table E-16

Summary of Cost-Benefit Measures for Two Alternative VSLs

Cost-Benefit Measures	\$5.3 Million VSL		\$13.2 Million VSL	
	3%	7%	3%	7%
Breakeven (CY)	2031 – 2034	2031 – 2035	2029 – 2030	2029 – 2031
Cost-Effectiveness (MY)	2024 – 2027	2025 – 2027	2024 – 2026	2024 – 2026
Positive Net Benefits (MY)	2025 – 2027	2025 – 2027	2024 – 2026	2024 – 2026

CY: calendar year, MY: model year of vehicles

<u>Uncertainty Analysis</u>

The uncertainty analysis examines the effects of various factors with appreciable variations on cost-benefit measures. The analysis identified safety target population, system effectiveness (i.e., app effectiveness), app adoption rates, and the overall costs (i.e., combining all cost factors) as the significant factors that mostly likely would perturb the cost and benefit estimates. With the proposed rule, the agency is entering a new era of traffic safety. With this in mind, the analysis took a conservative approach for describing the possible variability for these significant factors. Specifically, the analysis used a conservative range of app effectiveness rates. The analysis showed that the proposed rule would reach the breakeven year between 2030 and 3034 with 90 percent certainty. The most conservative scenario showed that the breakeven year would be five (at 3 percent discount) or six (at 7 percent discount) years later than the primarily estimated years. The cost-effectiveness and net-benefits analyses resulting from the uncertainty analysis showed that the proposed rule would be cost-effective and would accrue positive net benefits between MY 2024 and MY 2027 with 90 percent certainty or, at most, one MY later than the primary estimated MYs. The most conservative scenario showed two to three MYs later than the primary estimated MYs. Table E-17 summarizes the analysis results on breakeven, cost-effectiveness, and net-benefits for the 3 and 7 percent discount rates.

[22] No impact on the MY outcome. However, the cost per equivalent life saved and net-benefits varied with VSLs.

Table E-17
Summary of Uncertainty Analysis Results

Breakeven Year

	Discount Rate	
	3%	7%
Range	2027 – 2036	2027 – 2037
Most Likely Year	2030 – 2032	2031 – 2032
90% Certainty	2030 – 2033	2030 – 2034

MYs that Would Be Cost-Effective

	3%	7%
Range	2022 – 2028	2022 – 2028
Most Likely MY	2024 – 2026	2024 – 2026
90% Certainty	2024 – 2026	2024 – 2027

MYs that Would Accrue Positive Net Benefits

	3%	7%
Range	2022 – 2028	2022 – 2029
Most Likely MY	2024 – 2026	2025 – 2027
90% Certainty	2024 – 2027	2024 – 2027

Summary of Monetized Benefits and Costs

Annual Benefits and Costs

Table E-18 summarizes annual costs and undiscounted annual monetized benefits and net benefits for 40 years. As described earlier, annual estimates are the collective cost and benefit impacts from all applicable MY vehicles for a calendar year. The annual estimates were only discounted back to the time when the proposed rule is implemented for the breakeven analysis. Note that the upper range of the estimated benefits might be slightly lower than the maximum annual benefits which would occur after 43 years after the implementation of the proposed rule.

Table E-18
Summary of Annual Costs and Monetized Benefits for 40 Years*
(2014 Dollars)

	Costs	Total Monetized Benefits**	Net Benefits**
Undiscounted	$2.2 to $5.0 B	Up to $73.9 B	Up to $70.1 B

B: billion
*Note: Does not include spectrum opportunity costs, which will be included in the analysis of the final rule.
**The upper bound of estimates represents the benefits for 2060

MY Benefits and Costs

Table E-19 summarizes discounted MY costs, monetized MY benefits, cost per equivalent life saved, and net benefits for 30 model years of vehicles (MY 2021-2050). As described earlier, the MY costs were discounted primarily due to the discounted lifetime fuel economy impact. MY benefits represent the lifetime benefits for a MY vehicles and are required to be discounted. Note that for MY costs and net cost per equivalent life saved, there is no noticeable difference between the 3 and 7 discounted estimates. This is due to rounding errors and the small variations between the 3 and 7 percent discounted values for these two measures.

Table E-19
Summary of MY Costs and Monetized Benefits for 30 MY Vehicles
(2014 Dollars)

Discount Rate	Costs	Total Monetized Benefits*	Net Cost Per Equivalent Life Saved**	Net Benefits
At 3% Discount	$2.2 to $5.0 B	Up to $54.5 B	Up to $2.9 B	Up to $50.6 B
At 7% Discount	$2.2 to $5.0 B	Up to $47.6 B	Up to $2.9 B	Up to $43.8 B

B: billion
*The upper bound of estimates represents the benefits for 2050 MY vehicles.
** The upper bound of estimates represents the total costs for 2021 MY vehicles since no benefits are expected for that MY vehicles due to the 0 percent app adoption.

CHAPTER I. INTRODUCTION

This Preliminary Regulatory Impact Analysis (PRIA) accompanies NHTSA's Notice for Proposed Rulemaking (NPRM) to establish Federal Motor Vehicle Safety Standard (FMVSS) No. 150, Vehicle-to-Vehicle (V2V) Communication Systems, which would require passenger cars, multipurpose passenger vehicles (MPVs), trucks, and buses that have a gross vehicle weight rating (GVWR) of 4,536 kg (10,000 pounds) or less to be equipped with V2V communication capability, such that they will send and receive standardized Basic Safety Messages (BSMs) to and from other vehicles.

The proposed rule is complex and covers a wide range of areas; some are outside of the agency traditional regulatory boundary. The primary covered areas include communication technology, BSM format and communication protocols, spectrum use, BSM authentication, misbehavior detection and reporting, cybersecurity, and consumer privacy. Specifically, in communication technology, BSM authentication, and, misbehavior detection and reporting, the agency is trying to be comprehensive for each of these areas.

For V2V communication, the agency proposes to mandate dedicated short range communication (DSRC) technology while also allowing provisions for alternative technologies that are interoperable with DSRC as the agency recognizes the potential for innovation from other wireless communication technologies.

The proposed requirements for message authentication, misbehavior detection and reporting are to ensure a secure communication environment. For message authentication, the agency proposes that all V2V devices sign and verify their basic safety messages using a Public Key Infrastructure (PKI) –based Security Credential Management System (SCMS) in accordance with performance requirements and test procedures for BSM transmission and the signing of BSMs. In addition, the agency considers two alternatives. The first alternative is that the agency does not specify architecture or technical requirements for message authentication. Under this alternative, a receiver of a BSM message must be able to validate the contents of a message such that it can reasonably confirm that the message originated from a single valid V2V device, and the message was not altered during transmission. The second alternative is that the agency does not propose a specific message authentication requirement. BSM messages would still be validated with a checksum, or other integrity check, and be passed through a misbehavior detection system to attempt to filter malicious or misconfigured messages. Implementers would be free to include message authentication as an optional function.

For the misbehavior detection and reporting, the agency proposes to mandate requirements that would establish procedures for communicating with a SCMS (PKI or other system) to report misbehavior; and learn of misbehavior by other participants. This includes detection methods for a device hardware and software to ensure that the device has not been altered or tampered with from intended behavior. The alternative we proposed is that the agency would not to issue the requirement to report misbehavior or implement device blocking based to an authority. However, this proposed alternative would require implementers to identify methods that check a devices' functionality, including hardware and software, to ensure that the device has not been altered or tampered with from intended behavior. Implementers would be free to include misbehavior detection and reporting and as optional functions.

In addition, the agency research on message authentication is based on a PKI-based SCMS. Therefore, the requirement discussions and benefit and cost analysis in this PRIA are exclusively for this DSRC/PKI-based proposal. **(**For streamlining the discussion, the "proposed rule" is referring to DSRC/PKI-based proposal, hereafter. All discussions, unless noted otherwise, on proposed requirements are for this proposal.)

DSRC is a Wi-Fi type two-way short to medium-range communication capability. When implemented, vehicles can transmit and receive safety-critical messages to and from surrounding vehicles at the 5.8-5.9 gigahertz (GHz) frequency. DSRC has low latency and high reliability characteristics. Therefore, DSRC is an appropriate technology solution for enabling communication-based safety applications suitable specifically for the dynamic traffic/roadway environment. Furthermore, DSRC has a 300-meter transmitting range and a 360-degree unobtrusive detection angle that surpass the sensing capability of sensors, (i.e., cameras, radars, and lidar) currently used in vehicles. Therefore, with better sensing capability (range and area) and dynamic safety messages, the V2V-based safety applications (apps) will further reduce the number and severity of motor vehicle crashes and minimize the societal costs resulting from these crashes.

A V2V system includes three major entities: vehicles with DSRC units and safety apps, a message authentication approach for helping ensure a secure environment and seamless operations, and DSRC roadside equipment and other communication network (i.e., cellular, Wi-Fi, and Satellite) for supporting vehicle-to-infrastructure communication. Essentially, DSRC units in vehicles send out and receive standardized BSMs from nearby vehicles. The safety apps use the BSMs to determine whether the presence of other vehicles pose a crash risk and issue warnings to the driver if a risk exists. For V2V, it is critical that users of the network be able to have as much confidence as possible in the messages received.

This PRIA examines the safety impact and costs of the proposed rule. This proposed rule is made pursuant to the authority granted to NHTSA under the National Traffic and Motor Vehicle Safety Act ("Motor Vehicle Safety Act"). Under 49 U.S.C. Chapter 301, Motor Vehicle Safety (49 U.S.C. 30101 et seq.), the Secretary of Transportation is responsible for prescribing motor vehicle safety standards that are practicable, meet the needs for motor vehicle safety, and are stated in objective terms. The responsibility for promulgating of Federal motor vehicle safety standards is delegated to NHTSA.

NHTSA's standards, combined with State and local government efforts, market effects, and driver behavior improvements, have contributed to a significant reduction in highway fatalities and injuries - from 52,627 fatalities in 1970,[23] to 32,719 fatalities in 2013.[24] The reduction mostly has come from the crashworthiness standards as well as other behavioral changes, most notably the increase in safety belt use and the decline in impaired driving. However, the future

[23] National Highway Traffic Safety Administration, Traffic Safety Facts 2012. http://www-nrd.nhtsa.dot.gov/Pubs/812032.pdf

[24] National Highway Traffic Safety Administration, Fatality Analysis Report System (FARS) 2013 data. For more information, see www.nhtsa.gov/FARS

reduction, the agency believes will come from regulations for crash avoidance and active safety systems. With the advancement of sensing, electronic systems, and braking technologies, crash avoidance safety technologies have gradually been introduced into new vehicles. The agency has recognized the importance of these crash avoidance systems on the reduction of crashes and started to either establish rules requiring these technologies (e.g., ABS and ESC) or encourage the adaptation of these technologies using the agency's New Car Assessment Program (NCAP).[25] In February 2015 the agency announced that it would add two types of automatic emergency braking systems—crash imminent braking and dynamic brake support—to the list of recommended advanced safety features in our New Car Assessment Program, known to most Americans as NHTSA's Five Star Safety Ratings. However, due to the limitation of the sensor technologies on detection distance and field of view, certain prevalent crashes such as intersection crashes would not be reduced by current vehicle-resident sensing safety systems. The agency believes that V2V-based safety application systems (apps) can address the detection distance and field of view issues inherently in the vehicle-resident safety systems.

A. Crashes That Would Be Impacted by the Proposed Rule

Based on 2010-2013 General Estimates System (GES) and Fatality Analysis Reporting System (FARS), the most current real-world crash data available at the time of this analysis, there were 3.4 million (62 percent of all police-reported crashes) light-vehicle to light-vehicle (LV2LV) crashes, many of which can be addressed by this proposed rule.[26] About 7,325 fatalities and 1.8 million MAIS 1-5 injuries were associated with these LV2LV crashes.[27] Furthermore, these crashes damaged 4.7 million vehicles. In total, these LV2LV crashes cost society $319 billion.[28]

[25] In 2011, NCAP recommended Forward Collision Warnings, Lane Departure Warning, and Electronic Stability Control. These technologies would not impact across-path crashes and left-turning crashes – the two types of crashes that are the target population of the proposed rule.

[26] GES and FARS only record the police-reported crash severity scale known as KABCO: K=fatal injury, A= incapacitating injury, B=non-incapacitating injury, C=possible injury, O=no injury. These KABCO injuries then were converted to MAIS scale through a KABCO-MAIS translator. See the Benefit Chapter for details.

[27] MAIS (Maximum Abbreviated Injury Scale) represents the maximum injury severity of an occupant at an Abbreviated Injury Scale (AIS) level. AIS ranks individual injuries by body region on a scale of 1 to 6: 1=minor, 2=moderate, 3=serious, 4=severe, 5=critical, and 6=maximum (untreatable).

[28] Included in this monetized value as measured by the comprehensive costs are the cost of lost productivity, medical

Of these crashes, intersection crashes and left-turning crashes can thus far be best prevented by the V2V-based apps. Other types of crashes also can be further reduced by the V2V technology due to its improved sensing capability and the capability of a continuing communication of critical safety messages.[29]

B. Need for Regulation

The agency believes that without the requirement of V2V communication, the reduction of the above 3.4 million LV2LV crashes, especially the intersection crashes and left-turning crashes, is limited. As described earlier, due to the limitations of current vehicle-based sensors in terms of direction and distance, vehicle sensor-based safety systems will not likely be able to address intersection and left-turning crashes as effectively as V2V-based apps can. At this time, no other wireless technology has proven the ability to provide all of the critical attributes of DSRC needed to support V2V and V2I safety applications. Although commercial communications technologies continue to improve in terms of latency and security, none match DSRC performance capabilities or provide comparable user privacy controls.

The improvement in safety that results from enabling vehicles to communicate with one another depends directly on the fraction of the vehicle fleet that is equipped with the necessary technology, and on its ability to perform reliably. In turn, the effectiveness of any V2V communications technology depends on its ability to reliably transmit and receive recognizable and verifiable information using standardized protocols. Because the value to potential buyers of purchasing a vehicle that is equipped with V2V communications technology depends upon how many other vehicle owners have also purchased comparably equipped models, V2V communications has many of the same characteristics as more familiar network communications technologies. Historical experience indicates that in some markets involving new or innovative network technologies (mobile communications, for example), network-reliant products and the common standards necessary to enable them to interact can develop quickly and without government intervention.

In other cases, however, certain characteristics of these products can hinder the rate of diffusion of a developing network technology, so that the widespread adoption necessary for its success occurs more slowly or at a later date than its potential benefits to users would appear to justify. The agency believes that the network-based nature of V2V communications technology makes this likely be the case with vehicle-to-vehicle communications. Because V2V-equipped vehicles can exchange the information necessary to warn their drivers of impending crashes only with other similarly-equipped vehicles, a significant fraction of the safety benefits from preventing impending crashes that result from a vehicle buyer's decision to purchase a V2V-capable model is experienced by owners of *other* similarly-equipped vehicles.

Viewed another way, an important consequence of any improvement in fleet-wide vehicle safety that results from an individual buyer's decision to purchase a V2V-capable model is the resulting increase in the safety of occupants of other V2V-equipped vehicles. Thus the society-wide benefits of individual vehicle buyers' decisions to purchase V2V-capable models extend well beyond the direct increase in their own safety; in economic parlance, their decisions can confer external benefits on other travelers. Thus a significant "network externality" arises from a new vehicle buyer's decision to purchase a vehicle equipped to connect to the existing V2V communications network.

Conversely, however, the benefits that any individual consumer would receive from voluntary adoption of V2V are directly dependent on the voluntary adoption of this technology by other consumers. Unless individual buyers believe that a significant number of other buyers will obtain V2V systems, they are likely to conclude that the potential benefits they would receive from this system are unlikely to materialize. As a consequence, they are less likely to invest in V2V communications capabilities that would be would be justified by the resulting improvement in fleet-wide safety. The proposed requirement that all new vehicles be V2V-capable is thus likely to improve transportation safety more rapidly, effectively, and ultimately more extensively than would result from relying on the private decisions of individual vehicle buyers.

In addition to the partly external nature of safety benefits from V2V-capable vehicles, their extremely long product life places inherent constraints on the rate at which diffusion of new technologies throughout the entire vehicle fleet can occur. Thus in order to reach the critical mass of participants, a significant portion of the existing vehicle fleet will need replacement and a sustained, coordinated commitment on the part of manufacturers. Due to the inherent characteristics of the automobile market, manufacturers will inevitably face changing economic conditions and perhaps imperfect signals from vehicle buyers and owners, and these signals may not be based on complete information about the effectiveness of V2V technology, or incorporate the necessary foresight to value the potential life-saving benefits of V2V technology during the crucial phase of its diffusion. Without government intervention, the resulting uncertainty could undermine manufacturer plans or weaken manufacturers' incentive to develop V2V technology to its full potential.

C. Research Leading to the Proposed Rule

The U.S. Department of Transportation (USDOT), along with other research partners in State DOTs, academia, and industry, has been evaluating how to incorporate communication technology into transportation infrastructure since the mid-1980s, in order to improve transportation (particularly on-road vehicle) safety, mobility, and emissions. That broad research topic is generally referred to as "intelligent transportation systems" or "ITS." V2V research developed out of ITS research in the mid-2000s, when NHTSA and the Crash Avoidance Metrics Partnership (CAMP) began to look at the potential for DSRC as a vehicle communication technology, for the purpose of warning drivers of imminent crash risks in time to avoid them.

In the interest of brevity, NHTSA refers readers to the V2V Readiness Report[30] for a summary of the history of ITS research and NHTSA's work with CAMP and other partners prior to 2014. Based on the prior V2V research, the USDOT deployed a Safety Pilot Model (Model Deployment) from August 2012 to February 2014 in Ann Arbor, Michigan to test the V2V system and to support the estimation of the effectiveness of V2V technology at reducing crashes.

[30] DOT Docket NHTSA-2014-0022

Conducted by the University of Michigan Transportation Research Institute, the Model Deployment deployed prototype V2V DSRC devices on real roads with real drivers that interacted for over a year and provided the data that allowed the USDOT to evaluate the functional feasibility of V2V under real world conditions. Approximately 2,800 vehicles – a mix of cars, trucks, and transit vehicles operating on public streets within a highly concentrated area – were equipped with integrated in-vehicle safety systems, aftermarket safety devices, or vehicle awareness devices, all using DSRC to emit wireless signals of vehicle position and heading information. Vehicles equipped with integrated in-vehicle or aftermarket safety devices have safety apps that are able to warn drivers of an impending crash situation involving another equipped vehicle. Six V2V apps were tested in the Model Deployment. These apps are Intersection Movement Assist (IMA), Left-Turn Assist (LTA), Forward Collision Warning (FCW), Blind Spot Warning/Lane Change Warning (BSW/LCW), Enhanced Emergency Brake Warning (EEBW), and Do Not Pass Warning (DNPW).

The Model Deployment was the first and largest test of V2V technology in a real-world environment. Overall, the Model Deployment demonstrated that V2V technology can be deployed in a real-world driving environment. The experimental design was successful in creating naturalistic interactions between V2Vequipped vehicles that resulted in safety applications issuing warnings in the safety-critical driving scenarios that they were designed to address. The warnings generated and data about these warning events indicated that all the device demonstrated interoperability meaning all the devices could successfully communicate with each other. The Model Deployment was a key step in understanding the potential of this technology to assist drivers to avoid crashes and increase the safety of vehicle travel. These research programs led to NHTSA’s decision to initiate a rulemaking process on V2V.

In addition to the historical research on V2V prior to 2014, the V2V Readiness Report also identified a number of areas where additional research could be necessary either to develop mandatory requirements for new vehicles equipped with DSRC, or to further develop information needed to inform potential future requirements for DSRC-based safety applications. These research areas include (1) Spectrum Sharing and Interference, (2) DSRC Performance Requirements and Compliance Testing, (3) V2V Safety Application Improvement and

Performance Verification, (4) System Policy Need, (5) Security, and (6) Acceptance. The agency has conducted many research programs relating to these six arears after the publication of the V2V Readiness Report. Please consult the NPRM preamble for details.

D. ANPRM

On August 20, 2014, the agency published an ANPRM (79 FR 49270) in the Federal Register. Accompanying the ANPRM, the agency also published a research report discussing the status of V2V technology and its readiness for application ("V2V Readiness Report").[31] The ANPRM announced the agency's intent to move forward with the rulemaking process and stated our belief that a mandate to include DSRC devices in all vehicles would facilitate a market-driven approach to safety, and possibly other, application deployment.[32]

The ANPRM requested public comments on 57 questions.[33] These questions covered a variety of subjects including safety need, NHTSA's legal authority, technology and technical issues, safety applications, public acceptance, privacy, security, liability, potential cybersecurity threats[34], applicable standards, DSRC spectrum sharing, costs, and benefits.[35]

Through the ANPRM, the agency has collected valuable information and public comment on V2V technology, DSRC vs other communication protocols (e.g., satellite, cellular), the public key infrastructure for security, etc. The collected information is used to promulgate the NPRM.

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[31] Docket No. NHTSA-2014-0022-0001

[32] *Id.*

[33] 79 FR 49270, 49271

[34] *Id.* at 49273

[35] *Id.* *See also id.* at 49273-24

E. Comments to the ANPRM

In response to the ANPRM, the agency received more than 900 comments from a diverse set of commenters.[36] The comments include automobile manufacturers/suppliers, trade associations, standards development organizations, safety advocacy groups, individual citizens, technology/communications companies, other State/Federal agencies, and privacy groups. The comments also covered a wide variety of topics ranging from the technical details of V2V technology to the policy implications of any potential rule.

While expressing general support, the automotive manufacturers stated their belief that the Federal government needs to assume a large role in establishing key elements of the V2V environment (e.g., establishing common operating criteria for V2V devices, establishing a security credentials system, and preserving the 5.9 GHz spectrum for V2V safety).[37] The automotive manufacturer commenters discussed their legal concerns (including concerns over practicability of an FMVSS if certain aspects of the V2V environment are missing and potential legal liability for manufacturers).[38] While generally agreeing with our assessment regarding the readiness of some of the industry technical standards to ensure that V2V communications work, the automotive manufacturer commenters also emphasized the importance of privacy and public acceptance to the success of the technology.[39] In spite of some of these open policy and technical questions, many automotive manufacturer commenters also agreed that a regulation defining key items needed for interoperability is necessary to realize the full potential benefits of V2V.[40]

Automotive suppliers generally expressed support for the technology as well. They further generally opined that the technology and standards for the technology are mature enough for

[36] Docket No. NHTSA-2014-0022

[37] *See e.g.,* Comments from the Alliance of Automobile Manufacturers, Docket No. NHTSA-2014-0022-0603

[38] *See id.*

[39] *See id.*

[40] *See e.g.,* Comments from Ford Motor Company, Docket No. NHTSA-2014-0022-0953.

initial deployment. For example, DENSO[41] stated that DSRC is a suitable technology for implementing V2V safety applications and that the current BSM is adequate to support those purposes. Continental further commented that V2V demonstrations thus far show that the system works and is interoperable.[42] Raising different points, Delphi commented that the coverage of a potential V2V rule should include more than just vehicles contemplated in the ANPRM and that the technology should be developed in conjunction with the vehicle-resident systems.[43]

Safety advocacy groups also expressed support, but emphasized the importance of ensuring interference-free spectrum for V2V. For example, the American Motorcyclist Association stressed the need for interference-free spectrum to ensure the safety applications will function. V2V, in their view, has the unique capability to address crashes that represent a significant portion of motorcycle crashes (e.g., left turn across path crashes).[44] They also emphasized the importance of a uniform human-machine interface for safety applications (regardless of whether the applications use V2V or vehicle-resident based information).[45] Other safety advocacy groups (e.g., the Automotive Safety Council) covered a large variety of topics (e.g., emphasizing the importance of interoperability, the ability of V2V to work in conjunction with vehicle-resident systems, and expressed concern that the security system described in the report would not sufficient protect against all forms of "abuse" of the V2V environment).[46]

Two standards development organizations also submitted comments. The two organizations (SAE and IEEE) were involved in developing various standards incorporated in this proposed rule. Both generally expressed support for the agency's proposal and stated that—in spite of on-

[41] Docket No. NHTSA-2014-0022-0655

[42] Docket No. NHTSA-2014-0022-0414

[43] Docket No. NHTSA-2014-0022-0266

[44] Docket No. NHTSA-2014-0022-0646

[45] Consumers Union discussed the HMI and how warnings need to be effectively communicated to the driver. *See* Docket No. NHTSA-2014-0022-0533.

[46] *See e.g.,* Docket No. NHTSA-2014-0022-0511.

going research—the standards are mature enough to support deployment of DSRC devices and ensure that they are interoperable.[47] Where the standards organizations differed was their opinion concerning spectrum availability. SAE reiterated its concern that “interference-free spectrum” is critical for the V2V environment.[48] While IEEE suggested that spectrum sharing is feasible, they opined that DSRC deployment should not wait for further research on spectrum sharing.[49] Instead “acceptable sharing parameters” may be determined at a later date after DSRC deployment and further research.[50]

While expressing general support for the technology and NHTSA’s efforts in this area, technology/communications device manufacturers expressed two general concerns. Through their trade associations,[51] such manufacturers expressed concern over NHTSA’s authority to regulate software and mobile devices.[52] In addition, individual companies (e.g., Qualcomm[53]) and other associations (e.g., the Wi-Fi Alliance[54]) expressed their opinion regarding the viability of spectrum sharing with unlicensed Wi-Fi devices and the ability of V2V to flourish alongside other technologies that will benefit automotive and highway safety. Finally, the Information Technology Industry Council stated its belief that NHTSA needs to ensure that connected vehicle technologies are allowed to develop using different technological solutions (e.g., other communications mediums beyond DSRC).[55]

[47] *See e.g.,* Docket No. NHTSA-2014-0022-0597

[48] *See id.*

[49] *See* Docket No. NHTSA-2014-0022-0693.

[50] *Id*.

[51] CTIA—The Wireless Association and the Consumer Electronics Association

[52] *See e.g.,* Docket No. NHTSA-2014-0022-0483.

[53] Docket No. NHTSA-2014-0022-0665

[54] Docket No. NHTSA-2014-0022-0644

[55] Docket No. NHTSA-2014-0022-0403

Other government agencies also submitted comments. The NTSB commented that both V2V and vehicle-resident crash avoidance technologies are important and they are complementary—especially when one (vehicle-resident) fills the gap during the deployment of the other (V2V).[56] State agencies also commented.[57] AASHTO also mentioned that interference-free spectrum is critical and commented that supporting future upgrades to the system through software rather than hardware changes would be important for state agencies.[58]

A significant number of commenters also raised privacy concerns with this rulemaking. In addition to a large number of individual commenters, organizations such as EPIC stated that, since a potential rule would create significant privacy risks, they recommend that the government take various actions to protect the information (e.g., establish when PII can be collected, when/where information can be stored, additional encryption methods, and require adherence to Consumer Privacy Bill of Rights).[59] In addition, Professor Dorothy Glancy expressed concern that NHTSA plans to conduct its privacy analysis after the ANPRM stage of the rulemaking process and is concerned that not all potential data collection is accurately portrayed in the ANPRM.[60] On the other hand, while the FTC agreed that privacy concerns could exist in the V2V environment over (1) obtaining the vehicle location information and (2) pricing insurance premiums over the driving habits, it believes NHTSA has taken these concerns into account.[61]

[56] Docket No. NHTSA-2014-0022-0267

[57] State DOTs from also stress the need to have uniform HMI—serving a purpose similar to the MUTCD for traffic signs and signals. They also commented that other vehicle types that could benefit from V2V (e.g., vehicles with GVWR greater than 10,000) and mentioned the potential of other V2X applications (e.g., vehicle to rail, agricultural equipment, horse-drawn vehicles). Further they opine that mandate is needed to deploy quickly. *See e.g.,* Comment from PennDOT, Docket No. NHTSA-2014-0022-0371; TxDOT, Docket No. NHTSA-2014-0022-0218; Wisconsin DOT, Docket No. NHTSA-2014-0022-0507.

[58] Docket No. NHTSA-2014-0022-0420

[59] Docket No. NHTSA-2014-0022-0689

[60] Docket No. NHTSA-2014-0022-0331

[61] Docket No. NHTSA-2014-0022-0502

Finally, many individual citizen commenters (in addition to the topics covered above) expressed concerned about the potential of V2V technology on health. The EMR Policy Institute[62] expressed similar concerns stating that NHTSA should postpone this rulemaking until the FCC changes their guidelines regarding human radiation exposure to wireless communications.

Of these comments, the Alliance of Automobile Manufacturers, Inc. (the Alliance) and Fiat Chrysler Automobiles (Fiat-Chrysler) provided in-depth discussions on the cost and benefit analyses. The Alliance commented on several key elements that OMB requires on regulatory analyses were not provided in the V2V Readiness Report, such as addressing market failure and alternative regulatory approaches. Furthermore, the Alliance recommended the future regulatory analyses on V2V to include additional benefit and cost estimates. Fiat-Chrysler stated that the costs and benefits estimated in the ANPRM do not realistically represent the technology's effectiveness or cost burden. Please see Appendix B for our response to the cost and benefit specific comments.

F. SCMS RFI

In October, 2014 the agency published a Request for Information (RFI)[63] regarding a Security Credential Management System (SCMS) that could support a national deployment of a V2V communication system. The RFI asked 8 questions covering topics such as governance structures for the SCMS, the design of the SCMS, the necessary initial capital investment, the possible business model, financially sustainability of the SCSM (to ensure its uninterrupted operation), and the respondent’s interest in standing up and operating some or all of the components of a SCMS. In the ANPRM, the agency explained that NHTSA would not require the SCMS by regulation and did not expect to establish, fund or operate the SCMS.

The agency received 21 responses from vehicle manufacturers, software component developers and suppliers, cryptography experts, certificate management entities, satellite and cellular service

[62] Docket No. NHTSA-2014-0022-0682

[63] Docket No. NHTSA-2014-0023

providers and academia. Of these, 11 respondents indicated an interest in running some or all components of the SCMS. The remaining responses commented more generally on issues of potential governance and liability with two common themes: (1) that the Federal Government should take the lead in standing up and operating the SCMS; and (2) that the Federal Government should indemnify companies participating in the SCMS from liability.

Because the process of deploying cooperative V2V technology and supporting establishment of an SCMS both are unprecedented activities, the agency believed it would be beneficial to meet with the eleven respondents who expressed interest in operating the SCMS. The agency was able to meet with ten of the eleven respondents indicating interest in operating aspects of a potential SCMS. Through these meetings, the agency obtained valuable knowledge on cryptography intricacies, certificate distribution methodologies, root storage and protection, and the SCMS management. The agency also learned new potential stakeholders and service providers for SCMS.

In March of 2015, NHTSA initiated a project with CAMP to implement the SCMS Proof-of-Concept (PoC) system based on the revised SCMS design.[64] A key objective of the SCMS PoC is to bridge the gap between the SCMS utilized in the Safety Pilot Model Deployment and the national SCMS deployment in coordination with a final rule for light-vehicle DSRC devices. This is a two-year project which will result in the development and delivery of an operational SCMS. Please see the preamble for details.

Based on the comments from the ANPRM, the discussion from the meetings on the SCMS, and the SCMS PoC project, the agency is confident that the V2V environment can be established given the lead time and phase-in timeframe of the proposed rule.

G. V2V International and Harmonization Efforts

Canada, Europe, Japan, Korea, and Australia are also actively working on V2V technology. In North America, Canada has reserved spectrum of 5.9 GHz for V2X and is watching

[64] Docket No. NHTSA-2015-0060, Vehicle-To-Vehicle (V2V) Communications For Safety Research

developments in the U.S. closely. Significant V2V research and development activities have been completed and continue in both Europe and Asia. The real-world deployments in both continents focus more on V2I systems that can aid drivers and improve traffic flow. In Europe, the European Union organization DG CONNECT is responsible for conducting research and pilot projects related to connected vehicles. However, the EU's connected vehicle program focuses more on mobility and sustainability while the U.S. is more on vehicle safety applications. Another organization, Car 2 CAR Communications Consortium (C2C-CC) has been working closely with CAMP as part of the EU-US V2X Harmonization Program.

Japan, Korea and Australia in the Asia-Pacific region are most involved in DSRC-based V2X communications. In Japan, the Ministry of Land, Infrastructure, Transportation and Tourism's current V2X program is the adaptation Electronic Tolling system operating at 5.8 GHz. In addition, some Japanese OEMs (mainly Toyota) are actively supporting the deployment of V2X using 760 MHz communications. Message sets in Japan are still under development and appear to be moving to those harmonized between Europe and the U.S. Korea currently uses the 5.835 – 5.855 GHz band for Electronic Toll Collection and DSRC experimentation. Korea has performed field tests for V2V communication in this band. Industry sources indicate that Korea may shift DSRC for Intelligent Transportation Systems (ITS) to 5.9 GHz to be more aligned internationally. In Australia, Austroads, an association of Australian and New Zealand road transport and traffic authorities, is investigating potential spectrum interference issues. Austroads is working with some license holders to evaluate the feasibility of use of the 5.9 GHz spectrum for V2X in Australia. Another agency, Transport Certification Australia is leading the design for security requirements, supporting field deployments, and working with the Australian Communications and Media Authority (ACMA) on identifying requirements for spectrum usage. Because the Australian vehicle market is predominantly comprised of imports from the U.S., Europe, and Asia, these Australian agencies have joined in the international harmonization efforts to ensure that the vehicle brought into the country are interoperable with each other and with the new cooperative infrastructure equipment and applications emerging on the market.

The agency recognizes that harmonization of V2V technology will reduce costs and facilitate cross-border traffic (e.g., between NAFTA countries) and intends to implement harmonized standards if such standards can be accomplished. Since 2009, the US has collaborated with the European Commission (EC) on this effort. In 2009, the USDOT and EC signed a memorandum for an Implementing Arrangement for Cooperative Activities to develop V2X harmonized standards on transmitted message, security policy, and operating hardware and software.[65] The memorandum was renewed in December 2014. The harmonization and collaboration on standards is governed by a Harmonization Work Plan (HWP). Six harmonization task groups (HTGs), each focus on a specific subject, were established under the HWP:

- HTG1 on Security Standards
- HTG2 on Harmonization of US BSM and EU Cooperative Awareness Message
- HTG3 on Communications Standards
- HTG4/5 on Infrastructure Message Standards
- HTG6 on Harmonized Development of a Cooperative-ITS Security Policy Framework.

HTG group members comprise a small group of international experts who worked together intensively with co-leadership. Members are provided by the EC DG-CONNECT and USDOT, and typically chosen from among the editors of many of the current cooperative ITS standards in the different Standards Development Organizations (SDOs) providing direct linkages into those SDO activities, as well as representatives of the EU and USDOT and the Vehicle Infrastructure Integration Consortium (VIIC), and expert representatives from roadway and infrastructure agencies, system integrators, and policy analysts. HTG6 expanded the membership beyond the EC and USDOT to include Transport Certification Australia (TCA) plus observers from Canada and Japan.

H. Organization of the Remaining Analysis

The following outlines the remaining structure of this document. Chapter II discusses the requirements of the proposed rule. Chapter III discusses the V2V technology and how it works. Chapter VI examines the effectiveness of V2V-based safety applications. Chapter V estimates the annual benefits of the proposed rule and the lifetime benefits for model year (MY) vehicles. Chapter VI translates the benefits into monetized values. Chapter VII estimates the cost of the

[65] http://www.its.dot.gov/press/2015/euro_commission.htm#sthash.URMW4OOH.dpu

proposed rule including the annual cost and cost per MY vehicles. Chapter VIII provides breakeven analysis to determine the year that the cumulative annual benefits would be equal to the cumulative annual costs. Chapter IX provides the cost-effectiveness and net-benefits analyses to determine the first MY vehicles that would become cost-effective and accrue positive net benefits. Chapter X examines a regulatory alternative and its impacts. Chapter XI performs the probabilistic uncertainty analysis. Finally, Chapter XII examines the impacts of the proposed rule on small business entities. In addition, Appendix A provides background data such as vehicle sales and vehicle miles traveled that were used to estimate benefits and costs. Appendix B responds to cost-benefit related comments on the ANPRM.

CHAPTER II. REQUIREMENTS

This chapter briefly summarizes the requirements of the proposed rule (i.e., the DSRC/PKI-based proposal) to establish Federal Motor Vehicle Safety Standard (FMVSS) No. 150, Vehicle-to-Vehicle (V2V) Communication Systems. The proposed requirements covers a wide area of categories including the V2V communicating technology, the applicability of the proposed rule, lead time, BSM content and accuracy tolerance, BSM Transmission Protocol, message authentication, misbehavior detection and reporting, and consumer notice. The requirements are discussed in detail in the NPRM, but are too broad to be repeated in full here. Therefore, in addition to applicability and lead time, the PRIA only provides a condensed description on the performance requirements of BSMs, their transmitting protocol, and consumer privacy notice. The remaining requirement categories are closely associated with a PKI-based SCMS and test procedures and are not discussed here. Furthermore, as stated in the Introduction chapter, in addition to the DSRC as the proposed communication technology and PKI as the proposed SCMS for BSM authentication and misbehavior detection and reporting, the agency also proposes alternatives for communication technology, message authentication, and misbehavior detection and reporting. Readers should consult the discussions and regulatory texts in the NPRM preamble for details.

A. Applicability

The proposed rule would require passenger cars, multipurpose passenger vehicles (MPVs), trucks, and buses having a gross vehicle weight rating (GVWR) of 4,536 kilograms (kg; 10,000 pounds) or less to be equipped with V2V communication capability using dedicated short range communication (DSRC). Equipment subjected to the proposed rule includes those original DSRC-based safety equipment installed in the new applicable vehicles and aftermarket devices that are used to send and receive DSRC signals at the 5.850-5.925 GHz frequency (5.9 GHz band). This 75 MHz frequency band has been allocated by the FCC for DSRC applications and was configured into a 5 MHz guard band and seven 10 MHz channels. One of the channels serves as control channel that carries management data and designated high-priority data. The remaining six channels (service channels) would carry other types of data. Figure II-1 depicts the spectrum allocation for the 5.9 GHz band.

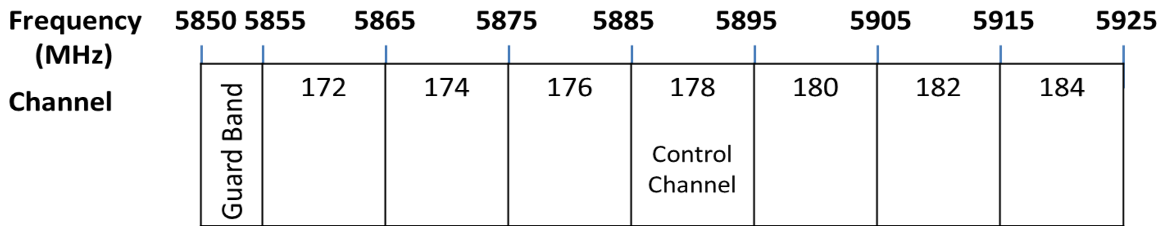

Figure II-1
The 5.9 GHz Spectrum Frequency Allocation

In this NPRM, the agency has decided to mandate V2V technology, but not mandate any specific apps. Due to cooperative nature of the technology, V2V can only function effectively when the participating vehicles can transmit the same information using the same protocol. V2V will be most successful when a significant level of adoption can be reached. Assuring that the adoption rate reaches a critical level removes the biggest obstacle from the deployment of V2V-based apps and thus encourages a free-market approach for apps.

Safety apps will provide consumers increased safety and other potential benefits. However, in contrast to the vehicle-resident safety systems that rely exclusively on the data from its own sensors and vehicle performance, the V2V-based apps require inputs from nearby vehicles. Therefore, these apps need to be designed to consider the variability of the incoming messages that would be sent from diverse vehicle models and production lines. This creates unique challenges for testing and deployment, and at this time, the agency believes that allowing a free-market approach for apps development is the preferred approach for considering these challenges.

B. Lead Time

The agency is proposing a three-year phase-in beginning two years after issuance of a final rule. The proposed phase-in rate for the three years is 50 percent, 75 percent, and 100 percent, respectively. The lead-time requirement was derived based on the agency's knowledge of suppliers' capacity and manufacturers' model reconfiguration cycle. The long lead time is intended to accommodate vehicle manufacturers' product cycles and reduce manufacturers' costs.

C. BSM Content and Performance Metrics

The proposed rule would require a message package containing a heading followed by safety elements. The heading provides the information needed for the device to properly process a sequence of messages. Safety elements are the data that would be used by vehicle safety apps. In addition, the agency proposes a time requirement and a vehicle position reference point for measuring vehicle location. Both are critical to the interoperation and interpretation of the safety elements. The safety elements are largely consistent with voluntary consensus standards from the Society of Automotive Engineers (SAE). No personal identifiable information such as driver's name, address, or VIN, is included in the BSMs.

<u>Package Heading</u>

Message heading contains the following three elements:

(a) Message ID
This data element informs the receiving device that the message is a BSM. The Agency proposes using "2" as the Message ID based on SAE Standard J2735.[66] The number "2" indicates the message is a basic safety message and should be interpreted accordingly.

(b) Message Count
Message Count helps the receiving device to order the message and know whether all messages from a sender were received. The Agency proposes the Message Count in a sequence between 0 and 127. This proposed sequence follows the requirements of the SAE standard J2735.

(c) Temporary Message ID.
Temporary Message ID allows a receiving device to associate a message to a sending device (e.g., 10 BSMs from Device 1 vs 5 BSMs from Device 2). The Agency proposes a randomly-generated 4-byte (32 bits) sequence number (i.e., 1 to 2^{32}) as specified in SAE Standard J2735 for Temporary Message ID.

[66] SAE Standard J2735, page 171

Safety Elements

The proposed rule specifies two parts of safety messages and their performance requirements (i.e., variation tolerance). Part I of BSM is a set of core data elements that would be required to transmit. The data elements in Part II would be required to be transmitted only under certain conditions. The proposed data elements primarily comprise of data elements from the current draft SAE standards[67] to facilitate interoperability between devices.

Part I of the BSM includes data elements about vehicle location, vehicle movement, basic vehicle motion, and vehicle size. The following shows these elements.

Vehicle Location:

(a) Longitudinal (x-measurement)

The agency is proposing that vehicles report a position that is within 1.5 meters (m) of their actual position at a Horizontal Dilution of Precision (HDOP)[68], measuring smaller than 5 within the 1 sigma absolute error. The 1 sigma absolute error accounts for the GPS variation from a vehicle's location due to reception of multiple satellite signals. The variation of 1.5 m variation is half of the width of a lane of traffic.

(b) Lateral (y-measurement)

Similar to the longitudinal measurement, the agency proposes that vehicles report a position that is within 1.5 m of their actual position at a Horizontal Dilution of Precision (HDOP) smaller than 5 within the 1 sigma absolute error. The variation of 1.5 m variation is half of the width of a lane of traffic.

(c) Elevation (z-measurement)

[67] E.g., SAE Standard J2735

[68] HDOP is a measure of the geometric quality of a GNSS satellite configuration in the sky. HDOP is a factor in determining the relative accuracy of a horizontal position based on the number of visible satellites. The smaller the DOP number, the better the geometry and accuracy. HDOP less than 5 is a general rule of indicating a good GNSS condition that can provide the desired level of accuracy. However, a lower DOP value does not automatically mean a low position error. The quality of a GPS-derived position estimate depends upon both the measurement geometry as represented by DOP values, and range errors caused by signal strength, ionospheric effects, multipath, etc.

The Agency proposes that vehicles report elevation in the BSM with an accuracy of 3 m (about 10 feet). The agency believes that the elevation measurement does not need to be as exact as the x and y-measurement but sufficient enough to distinguish between vehicles on the same level road vs those on an overpass structure.

Basic Vehicle Motion:

(d) Speed

The agency proposes the vehicle speed to be accurate within 0.35 meters per second (m/s; ~ 0.78 mph) of the actual speed and in 0.04 m/s increments.

(e) Heading

Heading in the BSM is defined as the angle in relation to the x-y plan of the vehicle position reference point (see Vehicle Position Reference Point below). The Agency proposes different accuracy requirements based on vehicle's speed:

- Within 2 degrees when the vehicle speed is greater than 12.5 m/s (~ 28 mph), and
- Within 3 degrees when the vehicle speed is less than or equal to 12.5 m/s.

In order to compensate the fact that GPS cannot be used to accurately determine the heading in very low speeds, the agency proposes that the last stored heading be used (i.e., "latch" [69]) when the vehicle drops below 1.11 m/s (~ 2.5 mph) and unlatch heading when its speed exceeds 1.39 m/s (~ 3.1 mph).

(f) Acceleration

The agency proposes that vehicles transmit the x and y-acceleration with an accuracy of 0.1 m/s^2 and vertical acceleration (i.e., z-acceleration) of 1 m/s^2.

(g) Yaw Rate

The agency proposes that Yaw Rate has an accuracy of 0.5 degrees per second.

[69] "Latch" in this context refers to a software operation that holds a value in memory and attached to a specific variable as long as a specified condition is reached and maintained.

(h) Transmission State

The agency proposes that vehicles transmit the transmission state of the vehicles indicating their gear direction (i.e., forward, neutral, or reverse).

(i) Steering Wheel Angle

The agency proposes the direction of the steering wheel angle transmit within 5 degrees of the actual steering wheel angle. This is one more element that can be used to confirm the actual heading of the vehicle.

(j) Vehicle Size

The agency proposes a 0.2 m tolerance for both vehicle length and width. The base vehicle length and width are those reported in the vehicle specifications. The Agency believes that the proposed 0.2 m tolerance can balance the need for accuracy and privacy protection.

The agency understands that brake applied status, traction control state, stability control status, auxiliary brake status, antilock brake status, brake boost status, and location accuracy could also be useful to vehicle safety. However, the Agency does not have enough information to determine the added contribution from these elements. Thus, the agency does not propose transmitting these data elements in the NPRM but might do so when sufficient information becomes available.

Part II includes (a) Path History data, (b) Path Prediction data, (c) Event Flags data elements conveying the sender's status with respect to safety-related events such as Antilock Brake System activation, Stability Control Activation, hard braking, and airbag deployment, and (d) Exterior Lights data elements including the status of turn signals. Path History can be used to enhance the warnings algorithm. Other data elements can be used to suppress warnings. Please consult the preamble for details.

Time

The agency proposes use of the UTC[70] standard for time and transmitting in an accuracy of 1 milliseconds (ms; i.e., within +/- 1 ms of the actual time). The UTC standard is widely accepted. It is also the predominant standard for time for internet devices and GPS devices which are relevant to DSRC devices.

Vehicle Position Reference Point

The agency proposes a vehicle position reference point as the point projected on the surface of the roadway of the center of a rectangle oriented about the vehicle's axis of symmetry front-to-back that encompasses the farthest forward and rearward points and side-to-side points on the vehicle including original equipment such as side view mirrors on the surface of the World Geodetic System-84 (WGS-84) ellipsoid. Figure II-2 illustrates the vehicle position reference point.

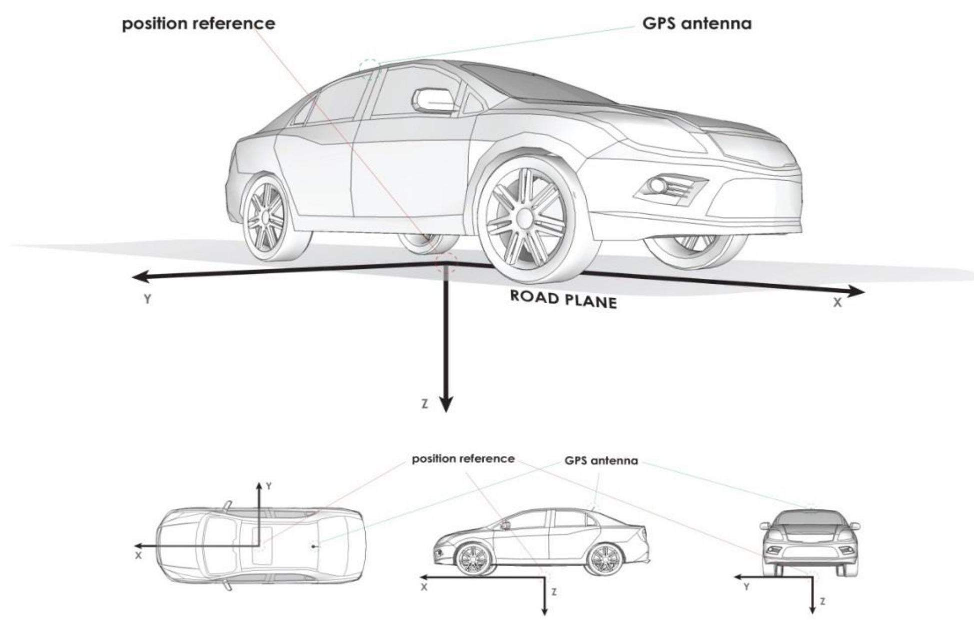

Figure III-2
Proposed Vehicle Position Reference Point

[70] Coordinated Universal Time International Telecommunications Union Recommendation (ITU-R TF.460-6), Standard-frequency and time-signal emissions. http://www.itu.int/dms_pubrec/itu-r/rec/tf/R-REC-TF.460-6-200202-I!!PDF-E.pdf

D. BSM Transmission Protocol

The proposed rule would require that all vehicles transmit the BSM on Channel 172 (5.855 to 5.865 GHz) at a data rate of at least 6 megabits per second (Mbps) with the maximum allowable 10 percent packet loss, i.e., package error ratio (PER) no more than 10 percent. Channel 172 is a 10 megahertz (MHz) channel based on the FCC's current rules that divides the V2V spectrum into various 10 MHz channels. A larger bandwidth is currently unavailable. Packet loss is measured as a percentage of packets lost with respect to packets sent. This PER level ensures that the delivery BSMs are sufficient for apps to function properly. The proposed rule would require the transmitting range of 300 meters and transmitting message at the 5.85-5.925 GHz frequency.

Furthermore, the proposed rule would require vehicles to transmit BSMs at a rate of 10 times per second or at a random time value within a specified range of time around each 1/10th of a second to reduce the probability of channel congestion. The proposed random time is 100 ms +/- a random value between 0 and 5 ms.[71]

E. Consumer Notice

The agency has proposed that motor vehicle manufacturers, at a minimum, include a standard V2V Privacy Notice in all owner's manuals (regardless of media) and in a publicly accessible web location that current and future owners may search by make/model/year to obtain the data access and privacy policies applicable to their motor vehicle, including those specifically addressing V2V data and functions. The text of the proposed V2V Privacy Notice is set forth in its entirety in the NPRM and the accompanying Privacy Impact Assessment. NHTSA feels strongly that V2V communications must be deployed consistent with the Fair Information Practice Principles, to the extent possible given the technical requirements of the system. In the context of a V2V system based on unencrypted broadcast messages, we view the critical consumer privacy issues as those of notice, transparency and data access – ensuring that the consumer has clear, understandable and transparent notice of the makeup of the V2V message

[71] CAMP document MPR-BSMTX-TXTIM-002

broadcast by mandated V2V equipment, who may access V2V messages emanating from a consumer’s motor vehicle, and how the data in V2V messages will or may be used. The agency strongly encourages consumers to read the Privacy Statements and Terms of Use applicable to third party applications prior to consenting. Please see NPRM for details.

CHAPTER III. HOW V2V WORKS

This chapter describes how the V2V system functions. A V2V system consists of three entities: DSRC technology (DSRC radios and apps) for sending and receiving communication signals, a message authentication approach for helping ensure a secure environment and seamless operations, and DSRC roadside equipment and other communication network (i.e., cellular, Wi-Fi, and Satellite) for supporting vehicle-to-infrastructure communication. The following describes the DSRC technology, message authentication, roadside equipment, and also the basic V2V operations.

A. DSRC Technology

DSRC is a two-way short to- medium-range wireless technology that provides nearly instantaneous network connectivity and message transmission. DSRC has low latency and high reliability characteristics. It provides a 300 meter transmitting range and a 360-degree unobtrusive detection angle. With a designated licensed bandwidth of 5.9 GHz, DSRC permits reliable communication. In addition, it provides very high data transmission rates in high-speed vehicle mobility conditions which are critical characteristics for detecting potential and imminent crash situations.[72]

B. Message Authentication

For a communication-based system, it is critical for the network users ensure a secure environment. The primary message authentication approach proposed is a Public Key Infrastructure (PKI) that provides public-key encryption and digital signature services is implemented to ensure a trustworthy network environment and address the fundamentals of security: authentication, confidentiality, integrity, non-repudiation and access control. The NPRM also discusses two alternative approaches to message authentication. SCMS is a PKI system that is designed specifically for the V2V environment. SCMS thus is a comprehensive system that comprises the hardware, software, people, policies, standards, and procedures needed

[72] Report and Order FCC-03-0324

to create, manage, distribute, monitor, and revoke digital certificates. The primary functions of SCMS are categorized below in alphabetical order:

- Certification Lab
- Intermediate Certificate Authority (Intermediate CA)
- Device Configuration Manager (DCM)
- Enrollment Certificate Authority (ECA)
- Linkage Authority (LA)
- Location Obscurer Proxy (LOP)
- Misbehavior Authority (MA)
- Pseudonym Certificate Authority (PCA)
- Registration Authority (RA)
- Request Coordination
- Root Certificate Authority (Root CA)
- SCMS Manager.

Table III-1 briefly describes the SCMS functions. Readers who are interested in the detail of SCMS design can consult the ANPRM[73] and the Agency's Request for Information (RFI)[74] regarding a Security Credential Management System (SCMS) that could support a national deployment of a V2V communication system. The goal of the SCMS design is to establish and maintain a trustworthy networking environment, while it provides an automatic and transparent system that is usable. Automation and transparency mean that all these activities will be performed primarily by machines and that drivers do not need to understand the backbone technology to operate in the V2V environment. In essence, SCMS serves as the governing and operational body of V2V communication.

[73] DOT Docket NHTSA-2014-0022

[74] DOT Docket NHTSA-2014-0023

Table III-1
SCMS Functions

Security Credentials Management System Functions		
Abbreviation	**Function Name**	**Activities**
Certification Lab	Certification Lab	Tests OBE and informs ECA that units of a particular type are eligible for enrollment certificates
DCM	Device Configuration Manager	Coordinates initial trust distribution with OBE and enables OBE to request certificates from RA
ECA	Enrollment Certificate Authority	Activates OBE and credentials users
Intermediate CA	Intermediate Certificate Authority	Shields Root CA from system and provides more flexibility for trust management
LA	Linkage Authority	Each pair of LAs communicates with RA to provide linkage values necessary for certificate production and assists the MA in misbehavior processes
LOP	Location Obscurer Proxy	Obscures the locations of requesting devices (e.g., OBE requesting certificates) from other functions, such as the RA
MA	Misbehavior Authority	Collects misbehavior reports from OBE and analyzes system-wide misbehavior. Coordinates with PCA and RA to produce CRL. Activities within the MA include: CRL generator, CRL broadcast, CRL store, Internal blacklist Manager (IBLM), and global detection.
PCA	Pseudonym Certificate Authority	Generates and signs short-lived certificates
RA	Registration Authority	Coordinates certificate production with other functions; sends certificates to OBE (during full deployment)
Request Coordination	Request Coordination	Coordinates certificate requests from OBE to RA
Root CA	Root Certificate Authority	Provides system wide trust through CME certificates issued to all CMEs; represents the basis of trust for the system
SCMS Manager	Security Credentials Management System Manager	Defines and oversees standards and practices for the SCMS, related to both technical and policy issues

The SCMS organizational design depends on the scope and responsibility of each function. Figure III-1 illustrates one design showing how these functions could be grouped based on whether the function can be owned by multiple organizations (Non-Central) or be best handled in a more centralized manner (Central). Currently, DOT is planning to work with SCMS design experts and SCMS "industry" participants to develop policies and procedures for an operational SCMS to support V2V.

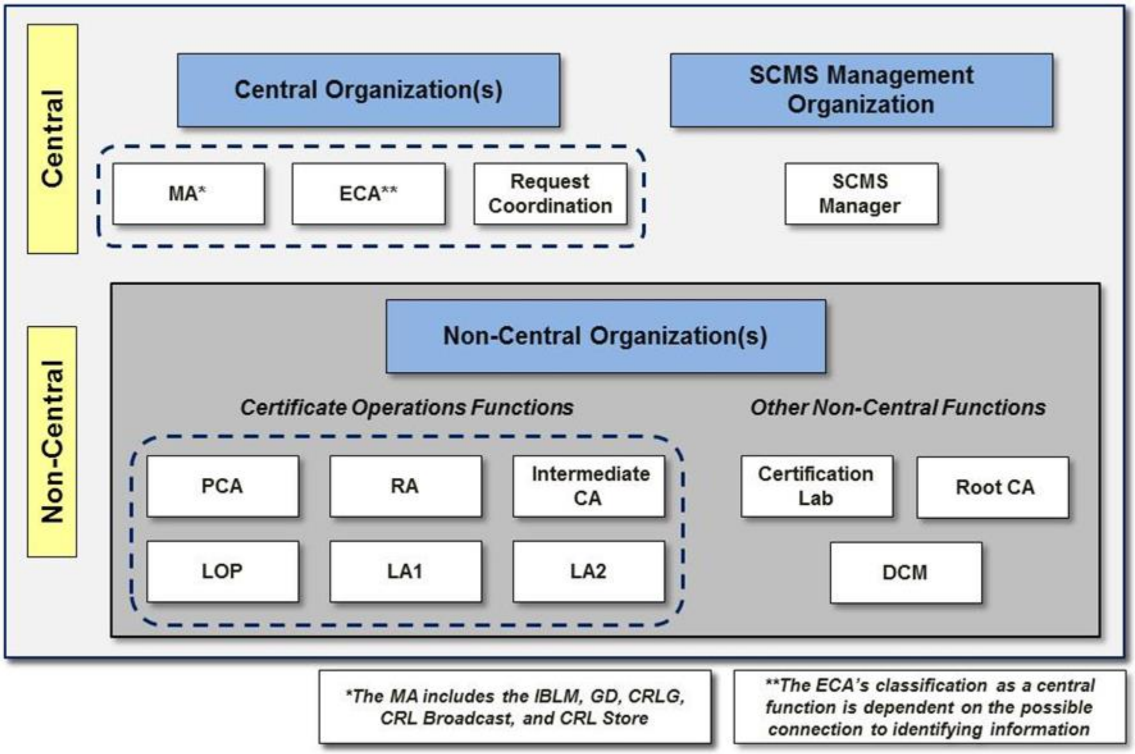

Figure III-1
SCMS Organization Model

As mentioned earlier, digital certificates are the core of a PKI system. To reduce privacy risks and promote security, the initial design of digital certificates is that a certificate is only valid for 5 minutes and completely discarded after use. This design was used in the Safety Pilot research. This approach required a large volume of certificates for a vehicle to manage, approximately 100,000 certificates for one year of operations. The researchers also determined that this approach would be inefficient since the majority of the time certificates were still expiring even when the vehicle was not in operation. Based on the lessons learned from this project, the researchers developed a more efficient design where a vehicle will have 20 valid certificates per week and change certificates at least once every 5 minutes. Under this design, only 1,050 certificates would be needed per year. Also, such a design would still help mitigate privacy risks by using certificates that rotate every five minutes and are valid only for one week. This alternative certificate usage model is currently under development and will be tested in the field as part of the on-going SCMS Proof-of-Concept projects.

C. Roadside Equipment and Other Communication Networks

Roadside equipment (RSE) is used to facilitate the communication between vehicles and SCMS. RSE is a small base station that would be needed to set up along the roadways and certain designated locations (e.g., dealership) to allow vehicles to "phone home (i.e., SCMS)" using DSRC. Through the RSEs, the vehicles can update certificates, report misbehaviors, receive certificate revocation lists (CRLs), and other traffic/safety updates. A separate DSRC radio and antenna in vehicle will be used exclusively for the communicating update. Therefore, two DSRC radios would be required for the DSRC-exclusive communication system, one designated for safety and the other one for supporting SCMS communication.

Other communication network systems include currently available communication technologies such as Wi-Fi, cellular, and satellite. These are alternative media to allow vehicles to phone-home or receive information from home (i.e., SCMS). If the vehicle comes equipped with alternative communication systems, only one DSRC radio is required in the vehicle for vehicle safety exclusive communication.

D. How V2V Functions Under DSRC and PKI

In the V2V operational environment with the primary message authentication proposal, all vehicles must obtain a registered identity from the SCMS to ensure secure information transfer. These identities are stored in a digital format known as a public key certificate in a PKI system. Therefore, all applicable vehicles need to enroll first in the SCMS to obtain a digital identity and digital certificates. After receiving the digital certificates from the SCMS, vehicles can send and receive BSMs to/from surrounding vehicles using DSRC at the 5.850-5.925 GHz frequency. The V2V-based apps then use BSMs to determine crash risk and issue warning if the risk exists.

SCMS creates digital certificates that securely bind the vehicles to their public keys and allows any tampering with the contents of the certificate to be easily detected. In creating certificates, SCMS acts as an agent of trust in a PKI. With these digital certificates, vehicles can authenticate the identity of the sender. The NPRM also discusses approaches for misbehavior detection and reporting including the primary proposal in which the SCMS also ensures that the certificate is still trustworthy at the time of use and revokes certificates that are no longer trustworthy. The revocation is done through CRLs which specify all revoked certificates. A CRL is a list of certificates that should not be trusted. When receiving a message, the vehicle will check the sender's certificate against those listed in the CRL. If a match occurs, the BSM is ignored. SCMS constantly updates CRLs and disseminates CRLs to vehicles. Vehicles use CRLs to discern whether to trust the received BSMs. The data transferring between vehicles and DSRC can be accomplished either through DSRC, RSE or other communication networks.

CHAPTER IV. EFFECTIVENESS OF IMA AND LTA

The analysis estimates crash avoidance and crashworthiness effects of two safety apps, Intersection Movement Assist (IMA) and Left Turn Assist (LTA), both of which the agency believes are only possible using V2V technology. IMA has the potential to reduce intersection crashes where vehicles were straight cross passing or where a vehicle turned into the same direction or opposite direction of another vehicle's path. LTA has the potential to reduce intersection crashes when a vehicle is making a left turn across the path of the other vehicle that is traveling straight from the opposite direction. Intersection crashes included intersection (signalized and non-signalized), intersection-related, driveway/alley, and driveway access related crashes. Note that in addition to IMA and LTA, four other safety apps, Forward Collision Warning (FCW)[75], Blind Spot Warning/Lane Change Warning (BSW/LCW)[76], Enhanced Emergency Brake Warning (EEBW)[77], and Do Not Pass Warning (DNPW)[78] were also tested in the Model Deployment. The agency was able to estimate the effectiveness of FCW and BSW/LCW.[79] However, the agency could not quantify their benefits due to lack of data to measure the incremental effects of these systems over the radar-based FCW and BSW/LCW. Therefore, the PRIA does not discuss the effectiveness of these two systems. EEBW and DNPW are also excluded from the discussion because of insufficient data at this time to assess their effectiveness.

The agency quantified the benefits of the proposed rule only from two safety apps – IMA and LTA. The crash avoidance effectiveness is determined by comparing crash rates of vehicles with (the treatment group) and without the app (baseline group). Crashworthiness effectiveness is

[75] Warns drivers of stopped, slowing, or slower vehicles ahead in the same traffic lane

[76] Alerts drivers to the presence of vehicles approaching or in their blind spot in the adjacent lane

[77] Warns drivers of another vehicle that is braking hard farther up ahead in the flow of traffic

[78] Warns the driver of one vehicle during a passing maneuver attempt when a slower-moving vehicle, ahead and in the same lane, cannot be safely passed using a passing zone that is occupied by vehicles in the opposite direction of travel.

[79] For FCW, effectiveness rates were estimated for three scenarios: 36% to 54% for lead vehicle stopped, 22% to 31% for lead vehicle moving, and 8% to 25% for lead vehicle decelerating. For BSW/LCW, the effectiveness is 8% to 10%.

determined by comparing injury probabilities of the treatment group to those of the control group. These effectiveness rates for an app can be mathematically noted by the following formula:

$$E=1-\frac{p_t}{p_c}$$

Where, E = Effectiveness of an app

P_t = crash rate (or injury probabilities) for the treatment group (i.e., vehicles with the app)

P_c = crash rate (or injury probabilities) for the control group (i.e., vehicles without the app.)

Since the V2V is an emerging technology and has not entered production, a statistical analysis of vehicles with and without the technology using real-world crash data is not feasible. Instead, the agency developed a computer simulation model - Safety Impact Methodology (SIM) [80] and a laboratory driver simulator (MiniSim) study to estimate the crash avoidance and crashworthiness effectiveness of V2V-based apps including IMA and LTA.[81]

The SIM is a personal computer-based simulation program that is developed by DOT's Volpe National Transportation Systems Center (VOLPE). The SIM contains several modules performing these functions: generating crash populations, building crash scenarios, establishing vehicle kinemics, simulating conflicts, and reporting results. Real world crashes data such as FARS, GES, and Crashworthiness Data System (CDS) can be used to categorize crash scenarios and establish the size of the crash problems. Event data recorder (EDR) information, when available, can also be used to supplement real-world crash data to determine pre-crash conditions and vehicle movements. The vehicle kinematic module contains basic kinematic equations of motion which were used for creating crash-imminent conflicts. The input values for kinematic

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[80] Yanagisawa, M., Razo, M., & Najm, W. G. (2015, August), Implementation of the Safety Impact Methodology Tool, National Highway Traffic Safety Administration, Washington, DC, Report No. DOT HS xxx xxx

[81] The agency examined 50 intersection or left turn across path crashes from the NASS data base for which we had event data recorder (EDR) information from both vehicles involved. Thus, we knew the velocity and brake activation of both vehicles from 5 seconds to 1 second before the crash. These analyses were used to determine that the SIM results did match very well with real crashes.

equations and for the valuables in other modules are assembled from several sources including Safety Pilot Model Deployment[82], the Integrated Vehicle-Based Safety System (IVBSS) field operational test[83], and MiniSim. Finally, the output and reporting module, as the name indicated, shows and outputs the simulation results.

Basically, SIM uses a Monte Carlo[84] simulation method to repeatedly simulate crash conditions to produce crash probabilities (or crash rate) for baseline cases (i.e., without V2V) and treatment cases (i.e., with V2V) for each app. For each condition, conflicts leading to that crash condition were generated using vehicle, environment, and human factors for simulation. Input values for each valuable that was used to generate these conflicts (e.g., driver response profile and braking force) are fitted by an appropriate probability distribution. Under the Monte Carlo simulation process, for each run (or trial), a value for each of the input variables was selected according to the chance from its probability distribution. Each trial ends with an outcome, a crash or no crash. Over a pre-defined number of trials or until certain performance criteria were met, a simulation produces many outcomes which then were used to calculate the probability of crashes. This process is run repeatedly for the control and treatment groups for each app. The crash probabilities of the control and treatment groups are then used to estimate the initial crash avoidance effectiveness for the app using the above formula. In addition to crash rates, SIM also produces impact speed distributions. These distributions are used as the proxy for delta-v for estimating the crashworthiness effectiveness of an app.

[82] A naturalistic driving test designed to collect data from integrated vehicles equipped with IMA, LTA, and FCW applications. In the first round, or 6-months, data from 64 integrated vehicles from the Model Deployment were used by SIM.

[83] A naturalistic driving test which collected data from 108 test subjects who drove vehicles equipped with an FCW application. Please consult *Integrated Vehicle-Based Safety Systems (IVBSS) Light Vehicle Field Operational Test Independent Evaluation*. DOT HS 811 516, October 2011.

[84] Monte Carlo is a probabilistic simulation technique which is used to address the uncertainty of predicted model outcome based on the uncertainty of inputs. For each input variable, the technique specifies its values by a probability distribution. For each simulation run, it selects a value for each variable from its probability distribution. The simulation process then can be repeated until specified criteria were met. Therefore, a Monte Carlo simulation could produce thousands or tens of thousands of possible predicted outcomes.

The **MiniSim** study uses a driver simulator to run experiments in a controlled environment. It was designed specifically for evaluating IMA and LTA in avoiding crashes. Drivers, both female and male, from various age groups were recruited to drive three IMA and two LTA crash scenarios. These drivers are divided into baseline (no V2V warning given) and treatment (V2V warning given to driver) groups.

<u>The design of MiniSim for IMA</u> is for drivers to experience <u>one</u> of the three driving conditions at a four-way intersection:

(1) The host vehicle (HV), i.e., the vehicle with IMA, driven by the study participants, approached the intersection with a green light and the remote vehicle (RV) came from the left running through a red light (PCP-M or perpendicular crossing path - moving)
(2) The HV approached the intersection with a stop sign and the RV came from the left (PCP-S or perpendicular crossing path - stopped)
(3) The HV approached the intersection with a stop sign and the RV came from the right (PCP-S)

In all conditions, the HV is traveling at 45 MPH toward the intersection and attempted to drive straight through. Just before crossing into the intersection, the RV, obscured by a stationary large truck, appears coming from the perpendicular/lateral side at a constant speed of 45 mph and is running through the stop sign or red light. If no action was taken by the driver of the HV, crash would occur in 3.3 seconds.

A total of 144 drivers balanced across age and gender, were recruited for the IMA experimental design. These drivers were equally divided into three groups (i.e., 48 each). Each group was to experience one of three driving conditions listed above. Each group is equally divided among three age groups (i.e., 18-24, 40-50, and 60 years old or more) and by gender (i.e., male and female). [85] In each of these groups, half of the drivers received an alert (i.e., Treatment) and half did not (Baseline).

[85] Balk, Stacy A., "Summary Report for a Simulator Study of Intersection Movement Assist (IMA) and Left Turn Assist (LTA) Warning Systems." Federal Highway Administration, Turner-Fairbank Highway Research Center, Internal Report, September 2013.

The MiniSim design for LTA is for drivers to experience one of the two following driving conditions while making a left turn at an intersection:

(1) The HV had a red light initially and had to stop and making a left turn when the light turned green (LTA-S crashes or left turn across - stopped)
(2) The HV had a green light and could make the turn without stopping (LTA-M crashes or left turn across - moving)

In both conditions, the HV and RV approached from the opposite directions. In addition, RV was obscured by a large truck in the opposite direction that was stopped in the left turning lane. As soon the HV started to initiate the turn and exceeded 6 MPH in speed, the RV appeared behind the stopped truck, traveling straight at a constant speed of roughly 45 MPH. The design scenario is to ensure that the two vehicles would collide in about 3.3 seconds if no action was taken by the HV.

A total of 96 drivers were recruited for the LTA experiment. These drivers were evenly divided into two groups, each experienced one of the designed scenarios above. Similar to the design for IMA, these drivers were balanced across gender and age groups and evenly divided into baseline and treatment groups. The collective crash rates for treatment and baseline groups were used to derive the crash avoidance effectiveness of LTA.

The initial crash avoidance effectiveness produced from the SIM simulation and MiniSim were used to derive the overall crash avoidance effectiveness of LTA and IMA. The process of deriving the crash avoidance effectiveness (E_a) can be briefly summarized by the following steps:

(1) Derive the individual E_a for various pre-crash scenarios and speed ranges (from SIM or MiniSim)
(2) Derive the overall E_a for each pre-crash scenario across all speed ranges
(3) Derive the system E_a across all pre-crash scenarios
(4) Derive the final system E_a by taking into account situations that were not addressed by SIM and MiniSim.

For crashworthiness effectiveness, E_w, the basic steps of deriving it is similar to that for crash avoidance. However, in this process, speed ranges were substituted by delta-v ranges and crash rates by injury probabilities. Change in injury probabilities between treatment and controls groups were due to the change in crash severity stemming from the driver's response to warnings. Crash severity generally is measured by delta-v. SIM produces impact speeds not delta-v. Therefore, the impact speeds were used as proxy for delta-v. The following sections will discuss these two processes in details.

A. Effectiveness of IMA

A.1 Crash Avoidance Effectiveness (E_a) for IMA

For IMA, the analysis used the SIM initial effectiveness outcome. For simulation, SIM developed crash scenarios according to the two pre-crash scenarios that correspond to the MiniSim design: perpendicular crossing path with both vehicles moving (PCP-M) and perpendicular crossing path with one vehicle going straight and another one first stopped and then proceeds (PCP-S). PCP-S crashes were further divided into two conditions by impact conditions (i.e., left and right). Brake reaction time and brake deceleration level collected by MiniSim were input into SIM to derive the initial E_a for various speed ranges for both PCP-M and PCP-S pre-crash scenarios. These initial E_a (i.e., step 1 of the process) were the basis for estimating the overall E_a for IMA.

<u>For the PCP-S scenario</u>, SIM simulates crash outcomes by remote vehicle (RV) traveling speeds and three separating distances between the HV (stopped and go vehicle) and its intersection point with the RV (going straight). The RV traveling speeds were grouped into five ranges: [10, 25), [25, 35), [35, 45), [40, 55), and 55+ mph where the symbol [x, y) represents that the speed is at least x mph but less than y mph and the plus symbol x+ represents that the speed is x mph and higher. The HV was at a complete stop and accelerated across intersection. The lowest speed of 10 mph is based on the current understanding that IMA would be activated when the RV was traveling at least 10 mph. The three separating distances are: 3-5 meters, 4 meters, and 5-8 meters. In addition, the simulation was further refined by the impact location of the RV (Left or

Right). The simulated crash probabilities for baseline and treatment groups were used to derive the initial E_a.

In total, SIM generated 30 initial E_a (5 speeds * 3 separating distance * 2 impact locations) for the PCP-S scenario. The next step is to aggregate these E_a across all speeds for each of the three separating distances. The aggregated results were represented by the weighted E_a over the five speed ranges and two impact locations. As such, the RV speed distribution of PCP-S crashes in all IMA crashes and the impact location proportion of PCP-S crashes were used as the weight. The weighted E_a can be derived using the following mathematical formula.

$$E_a = R \sum_{i=1}^{5} p_i * E_r^i + (1\text{-}R) \sum_{i=1}^{5} p_i * E_l^i$$

Where, E_a = weighted effectiveness over all speeds and impact locations

R = proportion of PCP-S right side impact

P_i = proportion of PCP-S in speed range i, with i=1 for [10, 25) and 5 for 50+ mph

E_r^i = effectiveness for speed range i for right side impact.

E_l^i = effectiveness for speed range i for left side impact.

Based on the knowledge we obtained from the model deployment, there are two possible operational designs for IMA. One design is that IMA can be activated only when the RV vehicle travels at least 25 mph. This activation threshold are likely be implemented by the near- future IMA. The other design eliminates this activation constraint and mostly likely reflects the future IMA. To address these two possible designs, the analysis used two different crash speed distributions as weights to estimate the weighted E_a: one that excluded the RV speed interval [10, 25) and one that included [10, 25). Essentially, the analysis treats the effectiveness of IMA as 0 for crashes in this speed range for the first case. Through this process, the initial 30 effectiveness rates were reduced to three ranges of weighted E_a. The lower bounds of these ranges were from the near-term design and the higher bounds were from the future design. Table IV-1 presents the process including the weights and the intial E_a that were used to calculate the weighted E_a.

As shown, IMA would avoid 15 - 24 percent of PCP-S crashes. These weighted E_a then will be combined with those of PCP-M to derive the final E_a for IMA. The wide range of effectiveness addresses the uncertainty concern on the inherent computation variations including those from SIM, MiniSim, and GES sampling errors.

Table IV-1
IMA Effectiveness for PCP-S Scenario

Percent of Crash distribution* by Remote Vehicle Traveling Speed (p_i)

Host Vehicle	Remote Vehicle Travel Speed (MPH)				
Speed (MPH)	**[10 , 25)**	**[25, 35)**	**[35, 45)**	**[45, 55)**	**55+**
[0 , 10)	11.39%	9.33%	8.97%	3.16%	1.28%

Percent of Impact Location*

Left Side Impact	48.25%
Right Side Impact	51.75%

* Already adjusted for unknown and served as weight for calculating weighted effectiveness;
Source: 2010-2013 GES

SIM Estimated Initial Effectiveness (E^i_{a1} and E^i_{a2})

Separating	Remote Vehicle Travel Speed (MPH)				
Distance (m)	**[10 , 25)**	**[25, 35)**	**[35, 45)**	**[45, 55)**	**55+**
Left Side					
3-5	0.64	0.66	0.66	0.67	0.67
4	0.65	0.67	0.67	0.67	0.68
5-8	0.70	0.70	0.70	0.70	0.70
Right Side					
3-5	0.68	0.70	0.71	0.71	0.72
4	0.69	0.71	0.72	0.72	0.72
5-8	0.74	0.75	0.50	0.75	0.75

Source: SIM simulation output

Weighted Effectiveness (E_a) for PCP-S

	Separating Distance		
	3-5 meters	4 meters	5-8 meters
Low Bound (excludes 10-25 mph)	0.16	0.16	0.15
High Bound (includes 10-25 mph)	0.23	0.23	0.24

<u>For the PCP-M scenario</u>, since both HV and RV were moving, the SIM simulates crash outcome based on the tabulation of HV and RV traveling speeds. Both traveling speeds were grouped into five speed ranges: [10, 25), [25, 35), [35, 45), [40, 55), and 55+ mph. Therefore, a total of

25 initial E_a were generated. As described earlier, the next step is to calculate the weighted E_a over all speed ranges. This weighted E_a represents the overall IMA effectiveness against PCP-M crashes. Table IV-2 illustrates the process. As shown, IMA would prevent 28 - 32 percent of PCP-M crashes. Note that the lower bound of effectiveness reflects the current design of IMA that IMA will only be activated when the at least one vehicle speed is above 25 mph. Essentially, in this case, the analysis treats the initial effectiveness for the cell HV speed [10, 25), RV speed [10, 25) as 0 for the calculation of E_a. This cell is shaded gray in the table.

Table IV-2
IMA Effectiveness for PCP-M Scenario

Percent of Crash distribution* by Remote Vehicle Traveling Speed (p_i)

Host Vehicle	Remote Vehicle Travel Speed (MPH)				
Speed (MPH)	**[10 , 25)**	**[25, 35)**	**[35, 45)**	**[45, 55)**	**55+**
[10 , 25)	11.35%	10.51%	11.42%	4.60%	1.01%
[25, 35)	4.33%	3.66%	1.85%	1.18%	0.17%
[35, 45)	3.43%	1.18%	2.02%	0.67%	0.13%
[45, 55)	1.71%	0.40%	0.57%	0.87%	0.10%
55+	0.57%	0.10%	0.17%	0.03%	0.10%

*served as weight for calculating weighted effectiveness; already adjusted for unknown speed
Source: 2010-2013 GES

SIM Estimated Initial Effectiveness (E_a)

Host Vehicle	Remote Vehicle Travel Speed (MPH)				
Speed (MPH)	**[10 , 25)**	**[25, 35)**	**[35, 45)**	**[45, 55)**	**55+**
[10 , 25)	0.47	0.51	0.55	0.57	0.60
[25, 35)	0.41	0.50	0.56	0.59	0.63
[35, 45)	0.43	0.54	0.60	0.63	0.67
[45, 55)	0.46	0.58	0.63	0.66	0.69
55+	0.49	0.62	0.66	0.67	0.69

Source: SIM simulation output

Weighted Effectiveness (E_a) for PCP-M

Low Bound	High Bound
28%	32%

For the overall IMA crash avoidance effectiveness, i.e., PCP-S and PCP-M combined, the effectiveness is simply the sum of these two weighted effectiveness rates since the weighted effectiveness for PCP-S and PCP-M already took into account its corresponding crash proportion,. Therefore, we estimate that IMA would avoid 43 - 56 percent of the intersection crashes (adding 15 to 24 percent for PCP-S to 28 to 32 percent for PCP-M). Table IV-3 shows the system effectiveness of the IMA.

Table IV_3
System Effectiveness for IMA

Low Bound	High Bound
43%	56%

A.2 Crashworthiness Effectiveness (E_w) for IMA

As described previously, crash impact speed distributions generated by SIM were used as the proxy for delta-v distributions for measuring the crash severity. Half the mid-point for each pre-defined impact speed interval serves as the delta-v for that interval since in the simulation both HV and RV were assumed to have the same mass. Injury probabilities by delta-v replaced crash rates to calculate the E_w. Of the real-world crash data systems that are maintained by the agency, only CDS reports delta-v. Therefore, CDS were used to derive the injury probabilities by delta-v (i.e., injury probability curves). Crashes from GES were used as weights to calculate the final delta-v that would reflect the real-world crash outcome.

<u>For the PCP-S scenario</u>, SIM simulated 30 crash conditions (i.e., 5 RV traveling speeds, 2 impact locations, and 3 separating distances) as discussed in the crash avoidance subsection and generated delta-v (i.e., half of the impact speed) distribution for each of these simulated conditions as shown in Tables IV-4 and IV-5. Table IV-4 is for the baseline group and the Table IV-5 is for the treatment group. Table IV-6 shows the average delta-v which was derived by multiplying the delta-v by its corresponding distribution percentage. Applying the crash distribution based on RV traveling speed categories (Table IV-7) to the average delta-v derives the delta-v for an average PCP-S crashes as shown in Table IV-8. These average delta-vs will be combined with that of PCP-M to present the overall delta-v level for an average IMA crash. As shown in Table IV-8, the average delta-v ranged from 4.19 to 5.18 mph for baseline crashes (without V2V) and 3.88 to 4.65 mph for treatment crashes (with V2V). This tells us that when a driver is stopped at an intersection, decides to go, and has a crash, the difference in the delta V of

that crash with or without a V2V warning is relatively small. The real benefit of V2V relates to the go/no go decision, and avoiding the crash by V2V warning the driver of the impending crash and the driver deciding not to go into the intersection or stopping in time before entering into the crash zone with the other vehicle.

Table IV-4

PCP-S Scenario - Delta-V* distribution by Remote Vehicle Traveling Speed

Baseline (Without V2V)

	Left Side Impact					Right Side Impact				
Delta-V	Remote Vehicle Travel Speed (MPH)					Remote Vehicle Travel Speed (MPH)				
(MPH)	**[10, 25)**	**[25, 35)**	**[35, 45)**	**[45, 55)**	**55+**	**[10, 25)**	**[25, 35)**	**[35, 45)**	**[45, 55)**	**55+**
Separating Distance: 3-5 Meters										
0.75	8.0%	6.6%	6.1%	6.5%	6.6%		6.6%	6.1%	6.5%	6.6%
2.25	25.2%	21.2%	20.4%	21.7%	19.7%		21.1%	20.5%	21.8%	19.6%
3.75	43.4%	42.5%	43.0%	40.6%	41.7%		42.3%	43.2%	40.8%	41.6%
5.25	9.1%	6.6%	7.5%	9.1%	9.7%		6.6%	7.6%	9.1%	9.7%
6.75	3.8%	0.0%	0.0%	0.0%	0.0%		0.0%	0.0%	0.0%	0.0%
8.25	3.6%	0.0%	0.0%	0.0%	0.0%		0.0%	0.0%	0.0%	0.0%
9.75	3.6%	0.0%	0.0%	0.0%	0.0%		0.0%	0.0%	0.0%	0.0%
11.25	3.1%	0.0%	0.0%	0.0%	0.0%		0.0%	0.0%	0.0%	0.0%
12.75	0.2%	7.3%	0.0%	0.0%	0.0%		7.2%	0.0%	0.0%	0.0%
14.25	0.0%	7.1%	0.0%	0.0%	0.0%		7.0%	0.0%	0.0%	0.0%
15.75	0.0%	6.4%	0.0%	0.0%	0.0%		6.4%	0.0%	0.0%	0.0%
17.25	0.0%	2.3%	5.4%	0.0%	0.0%		2.3%	5.4%	0.0%	0.0%
18.75	0.0%	0.0%	7.1%	0.0%	0.0%		0.0%	7.1%	0.0%	0.0%
20.25	0.0%	0.0%	7.2%	0.0%	0.0%		0.0%	7.3%	0.0%	0.0%
21.75	0.0%	0.0%	3.2%	4.2%	0.0%		0.0%	3.3%	4.2%	0.0%
23.25	0.0%	0.0%	0.0%	18.0%	22.3%		0.0%	0.0%	18.1%	22.2%
Separating Distance: 4 Meters										
0.75	8.0%	5.7%	5.1%	4.3%	4.2%	8.3%	5.8%	5.1%	4.6%	4.3%
2.25	24.2%	21.7%	21.0%	20.5%	19.3%	25.3%	22.2%	20.7%	21.6%	19.4%
3.75	46.1%	46.8%	45.5%	44.2%	45.5%	48.2%	47.8%	45.0%	46.5%	45.9%
5.25	8.5%	6.7%	7.1%	9.7%	10.4%	8.9%	6.9%	7.1%	10.2%	10.5%
6.75	3.8%	0.0%	0.0%	0.0%	0.0%	4.0%	0.0%	0.0%	0.0%	0.0%
8.25	3.3%	0.0%	0.0%	0.0%	0.0%	3.4%	0.0%	0.0%	0.0%	0.0%
9.75	2.8%	0.0%	0.0%	0.0%	0.0%	2.9%	0.0%	0.0%	0.0%	0.0%
11.25	3.0%	0.0%	0.0%	0.0%	0.0%	3.1%	0.0%	0.0%	0.0%	0.0%
12.75	0.1%	6.3%	0.0%	0.0%	0.0%	0.1%	6.4%	0.0%	0.0%	0.0%
14.25	0.0%	5.9%	0.0%	0.0%	0.0%	0.0%	6.1%	0.0%	0.0%	0.0%
15.75	0.0%	5.4%	0.0%	0.0%	0.0%	0.0%	5.6%	0.0%	0.0%	0.0%
17.25	0.0%	1.4%	5.3%	0.0%	0.0%	0.0%	1.4%	5.3%	0.0%	0.0%
18.75	0.0%	0.0%	6.2%	0.0%	0.0%	0.0%	0.0%	6.1%	0.0%	0.0%
20.25	0.0%	0.0%	6.9%	0.0%	0.0%	0.0%	0.0%	6.8%	0.0%	0.0%
21.75	0.0%	0.0%	2.8%	3.8%	0.0%	0.0%	0.0%	2.8%	3.9%	0.0%
23.25	0.0%	0.0%	0.0%	17.5%	20.6%	0.0%	0.0%	0.0%	18.4%	20.8%

Separating Distance: 5-8 Meters										
0.75	4.9%	2.4%	1.0%	0.7%	0.0%	4.7%	2.1%	0.9%	0.6%	0.0%
2.25	23.5%	15.8%	9.4%	9.5%	10.3%	22.3%	13.8%	8.6%	8.7%	8.8%
3.75	33.6%	30.4%	31.4%	33.3%	28.4%	31.8%	26.5%	28.5%	30.5%	24.3%
5.25	31.7%	38.9%	46.7%	42.7%	45.5%	30.1%	33.9%	42.4%	39.2%	38.8%
6.75	4.2%	6.0%	4.6%	6.0%	7.9%	4.0%	5.2%	4.1%	5.5%	6.8%
8.25	0.7%	0.0%	0.0%	0.0%	0.0%	0.7%	0.0%	0.0%	0.0%	0.0%
9.75	0.7%	0.0%	0.0%	0.0%	0.0%	0.6%	0.0%	0.0%	0.0%	0.0%
11.25	0.7%	0.0%	0.0%	0.0%	0.0%	0.6%	0.0%	0.0%	0.0%	0.0%
12.75	0.0%	1.5%	0.0%	0.0%	0.0%	0.0%	1.3%	0.0%	0.0%	0.0%
14.25	0.0%	2.2%	0.0%	0.0%	0.0%	0.0%	1.9%	0.0%	0.0%	0.0%
15.75	0.0%	2.3%	0.0%	0.0%	0.0%	0.0%	2.0%	0.0%	0.0%	0.0%
17.25	0.0%	0.4%	2.1%	0.0%	0.0%	0.0%	0.4%	1.9%	0.0%	0.0%
18.75	0.0%	0.0%	2.9%	0.0%	0.0%	0.0%	0.0%	2.7%	0.0%	0.0%
20.25	0.0%	0.0%	0.8%	0.0%	0.0%	0.0%	0.0%	0.7%	0.0%	0.0%
21.75	0.0%	0.0%	1.0%	0.7%	0.0%	0.0%	0.0%	0.9%	0.6%	0.0%
23.25	0.0%	0.0%	0.0%	7.2%	7.9%	0.0%	0.0%	0.0%	6.6%	6.8%

*equivalent to half of the crash impact speed
Source: SIM simulation output

Table IV-5
PCP-S Scenario - Delta-V* distribution by Remote Vehicle Traveling Speed
Treatment (With V2V)

	Left Side Impact					Right Side Impact				
Delta-V	Remote Vehicle Travel Speed (MPH)					Remote Vehicle Travel Speed (MPH)				
(MPH)	**[10, 25)**	**[25, 35)**	**[35, 45)**	**[45, 55)**	**55+**	**[10, 25)**	**[25, 35)**	**[35, 45)**	**[45, 55)**	**55+**
Separating Distance: 3-5 Meters										
0.75	16.7%	15.8%	16.5%	15.8%	16.3%		15.8%	16.5%	15.8%	16.3%
2.25	31.4%	30.6%	29.6%	31.5%	30.9%		30.6%	29.6%	31.5%	30.9%
3.75	29.7%	26.4%	27.5%	28.2%	27.2%		26.4%	27.5%	28.2%	27.2%
5.25	7.8%	4.5%	5.0%	3.6%	5.1%		4.5%	5.0%	3.6%	5.1%
6.75	3.9%	0.0%	0.0%	0.0%	0.0%		0.0%	0.0%	0.0%	0.0%
8.25	3.9%	0.0%	0.0%	0.0%	0.0%		0.0%	0.0%	0.0%	0.0%
9.75	3.8%	0.0%	0.0%	0.0%	0.0%		0.0%	0.0%	0.0%	0.0%
11.25	2.7%	0.0%	0.0%	0.0%	0.0%		0.0%	0.0%	0.0%	0.0%
12.75	0.2%	7.9%	0.0%	0.0%	0.0%		7.9%	0.0%	0.0%	0.0%
14.25	0.0%	7.3%	0.0%	0.0%	0.0%		7.3%	0.0%	0.0%	0.0%
15.75	0.0%	5.6%	0.0%	0.0%	0.0%		5.6%	0.0%	0.0%	0.0%
17.25	0.0%	1.9%	5.3%	0.0%	0.0%		1.9%	5.3%	0.0%	0.0%
18.75	0.0%	0.0%	6.5%	0.0%	0.0%		0.0%	6.5%	0.0%	0.0%
20.25	0.0%	0.0%	7.2%	0.0%	0.0%		0.0%	7.2%	0.0%	0.0%
21.75	0.0%	0.0%	2.4%	4.5%	0.0%		0.0%	2.4%	4.5%	0.0%
23.25	0.0%	0.0%	0.0%	16.4%	20.4%		0.0%	0.0%	16.4%	20.4%

Separating Distance: 4 Meters										
0.75	16.2%	16.1%	12.5%	13.3%	13.5%	16.2%	16.1%	12.5%	13.3%	13.5%
2.25	32.3%	31.2%	31.2%	32.5%	31.2%	32.3%	31.2%	31.2%	32.5%	31.2%
3.75	30.2%	28.0%	29.1%	28.5%	28.4%	30.2%	28.0%	29.1%	28.5%	28.4%
5.25	8.1%	5.7%	6.2%	5.8%	6.6%	8.1%	5.7%	6.2%	5.8%	6.6%
6.75	3.6%	0.0%	0.0%	0.0%	0.0%	3.6%	0.0%	0.0%	0.0%	0.0%
8.25	3.5%	0.0%	0.0%	0.0%	0.0%	3.5%	0.0%	0.0%	0.0%	0.0%
9.75	3.1%	0.0%	0.0%	0.0%	0.0%	3.1%	0.0%	0.0%	0.0%	0.0%
11.25	3.0%	0.0%	0.0%	0.0%	0.0%	3.0%	0.0%	0.0%	0.0%	0.0%
12.75	0.1%	6.9%	0.0%	0.0%	0.0%	0.1%	6.9%	0.0%	0.0%	0.0%
14.25	0.0%	5.6%	0.0%	0.0%	0.0%	0.0%	5.6%	0.0%	0.0%	0.0%
15.75	0.0%	5.2%	0.0%	0.0%	0.0%	0.0%	5.2%	0.0%	0.0%	0.0%
17.25	0.0%	1.5%	5.3%	0.0%	0.0%	0.0%	1.5%	5.3%	0.0%	0.0%
18.75	0.0%	0.0%	6.5%	0.0%	0.0%	0.0%	0.0%	6.5%	0.0%	0.0%
20.25	0.0%	0.0%	6.4%	0.0%	0.0%	0.0%	0.0%	6.4%	0.0%	0.0%
21.75	0.0%	0.0%	2.9%	4.1%	0.0%	0.0%	0.0%	2.9%	4.1%	0.0%
23.25	0.0%	0.0%	0.0%	15.8%	20.2%	0.0%	0.0%	0.0%	15.8%	20.2%
Separating Distance: 5-8 Meters										
0.75	9.5%	7.4%	4.9%	0.7%	2.1%	9.5%	7.4%	4.9%	0.7%	2.1%
2.25	35.8%	30.2%	31.5%	21.0%	22.7%	35.8%	30.2%	31.5%	21.0%	22.7%
3.75	34.9%	37.6%	31.0%	37.0%	39.2%	34.9%	37.6%	31.0%	37.0%	39.2%
5.25	14.8%	16.3%	23.4%	26.1%	22.7%	14.8%	16.3%	23.4%	26.1%	22.7%
6.75	2.2%	1.6%	1.1%	2.2%	3.1%	2.2%	1.6%	1.1%	2.2%	3.1%
8.25	1.0%	0.0%	0.0%	0.0%	0.0%	1.0%	0.0%	0.0%	0.0%	0.0%
9.75	1.0%	0.0%	0.0%	0.0%	0.0%	1.0%	0.0%	0.0%	0.0%	0.0%
11.25	0.7%	0.0%	0.0%	0.0%	0.0%	0.7%	0.0%	0.0%	0.0%	0.0%
12.75	0.0%	2.3%	0.0%	0.0%	0.0%	0.0%	2.3%	0.0%	0.0%	0.0%
14.25	0.0%	2.3%	0.0%	0.0%	0.0%	0.0%	2.3%	0.0%	0.0%	0.0%
15.75	0.0%	1.9%	0.0%	0.0%	0.0%	0.0%	1.9%	0.0%	0.0%	0.0%
17.25	0.0%	0.4%	3.8%	0.0%	0.0%	0.0%	0.4%	3.8%	0.0%	0.0%
18.75	0.0%	0.0%	2.2%	0.0%	0.0%	0.0%	0.0%	2.2%	0.0%	0.0%
20.25	0.0%	0.0%	1.6%	0.0%	0.0%	0.0%	0.0%	1.6%	0.0%	0.0%
21.75	0.0%	0.0%	0.5%	0.7%	0.0%	0.0%	0.0%	0.5%	0.7%	0.0%
23.25	0.0%	0.0%	0.0%	12.3%	10.3%	0.0%	0.0%	0.0%	12.3%	10.3%

*equivalent to half of the crash impact speed
Source: SIM simulation output

Table IV-6
Derived Average Delta-V (MPH) by Simulated Crash Conditions

Separating Distance (Meter)	Baseline					Treatment				
	Remote Vehicle Travel Speed (MPH)					Remote Vehicle Travel Speed (MPH)				
	[10, 25)	**[25, 35)**	**[35, 45)**	**[45, 55)**	**55+**	**[10, 25)**	**[25, 35)**	**[35, 45)**	**[45, 55)**	**55+**
Left Side Impact										
3-5	4.01	5.80	6.94	7.63	7.74	3.63	5.29	6.19	6.87	6.85
4	3.95	5.38	6.68	7.54	7.50	3.58	4.91	6.26	6.77	6.92
5-8	3.97	4.90	5.45	5.93	6.06	3.37	4.10	4.72	6.40	5.79
Right Side Impact										
3-5		5.78	6.98	7.68	7.72		5.29	6.19	6.87	6.85
4	4.12	5.50	6.60	7.93	7.57	3.58	4.91	6.26	6.77	6.92
5-8	3.77	4.27	4.95	5.44	5.18	3.37	4.1	4.72	6.40	5.79

Table IV-7
Traveling Speed Distribution*

Remote Vehicle Travel Speed (MPH)				
[10 , 25)	**[25, 35)**	**[35, 45)**	**[45, 55)**	**55+**
0.3014	0.2469	0.2374	0.0836	0.0339

*used as weight to calculate the delta-v level for an average PCP-S

Table IV-8
Delta-V for an Average PCP-S Crash

Separating Distance	Baseline	Treatment
3-5	5.18	4.65
4	5.04	4.58
5-8	4.19	3.88

For the PCP-M scenario, the process of deriving the delta-v for an average PCP-M crash is similar to that for PCP-S. The only difference between the two is the simulated crash conditions. There were 25 conditions for PCP-M, represent the combinations of 5 HV and 5 RV traveling speeds. Tables IV-9 to IV-12 show the parallel processes for generating an average crash delta-v for a PCP-M crash. As shown in Table IV-12, the delta-v for a baseline PCP-M is estimated to be 10.63 mph and for a treatment PCP-M is about 8.30 mph. Thus, when both vehicles are moving before an intersection crash, and the crash still occurs, IMA by providing a warning can reduce the delta-v of the crash by 2.33 mph on average.

Table IV-9

PCP-M Scenario - Delta-V* distribution by Remote Vehicle Traveling Speed

	Baseline					Treatment				
Delta-V	Remote Vehicle Travel Speed (MPH)					Remote Vehicle Travel Speed (MPH)				
(MPH)	**[10, 25)**	**[25, 35)**	**[35, 45)**	**[45, 55)**	**55+**	**[10, 25)**	**[25, 35)**	**[35, 45)**	**[45, 55)**	**55+**
Host Vehicle Traveling Speed **[10, 25)**										
0.75	0.5%	0.5%	0.2%	0.1%	0.0%	4.4%	1.6%	0.7%	0.4%	0.0%
2.25	1.8%	1.8%	1.6%	1.4%	0.9%	13.6%	8.8%	5.6%	4.5%	2.5%
3.75	5.4%	5.4%	5.6%	5.4%	5.0%	21.2%	20.2%	16.5%	15.1%	12.2%
5.25	18.2%	18.0%	18.4%	18.7%	18.7%	22.4%	24.3%	24.1%	23.6%	21.3%
6.75	20.5%	20.6%	20.9%	20.9%	21.1%	18.1%	20.9%	24.0%	25.0%	25.2%
8.25	20.3%	20.6%	20.1%	20.1%	20.4%	12.3%	14.4%	17.4%	19.0%	22.8%
9.75	18.8%	18.8%	18.5%	18.7%	19.1%	6.4%	7.6%	9.1%	9.6%	12.7%
11.25	14.1%	14.0%	14.1%	14.1%	14.2%	1.7%	2.2%	2.5%	2.8%	3.2%
12.75	0.5%	0.5%	0.5%	0.5%	0.5%	0.0%	0.0%	0.1%	0.1%	0.1%
14.25	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
15.75	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
17.25	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
18.75	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
20.25	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
21.75	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
23.25	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Host Vehicle Traveling Speed **[25, 35)**										
0.75	0.1%	0.0%	0.0%	0.0%	0.0%	0.6%	0.0%	0.0%	0.0%	0.0%
2.25	0.2%	0.0%	0.0%	0.0%	0.0%	2.8%	0.1%	0.0%	0.0%	0.0%
3.75	0.6%	0.2%	0.0%	0.0%	0.0%	6.5%	0.9%	0.1%	0.0%	0.0%
5.25	1.2%	1.0%	0.5%	0.1%	0.0%	11.7%	4.8%	1.4%	0.5%	0.0%
6.75	2.3%	2.3%	1.8%	1.2%	0.3%	16.0%	12.8%	6.9%	4.2%	0.9%
8.25	4.4%	4.7%	4.4%	4.1%	2.9%	17.7%	20.6%	17.1%	14.0%	7.7%
9.75	8.4%	8.4%	8.4%	8.4%	8.0%	16.9%	23.2%	25.5%	25.1%	21.7%
11.25	15.2%	15.4%	15.7%	15.8%	16.5%	14.2%	19.1%	24.1%	27.8%	30.3%
12.75	26.7%	26.6%	27.2%	27.6%	28.3%	9.1%	12.0%	15.8%	18.1%	24.9%
14.25	22.8%	23.1%	23.3%	23.9%	24.9%	3.6%	5.4%	7.6%	8.5%	11.9%
15.75	15.4%	15.7%	16.0%	16.2%	16.3%	0.8%	1.2%	1.4%	1.8%	2.6%
17.25	2.6%	2.5%	2.7%	2.7%	2.7%	0.0%	0.0%	0.0%	0.0%	0.0%
18.75	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
20.25	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
21.75	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
23.25	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Host Vehicle Traveling Speed **[35, 45)**										
0.75	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%
2.25	0.1%	0.0%	0.0%	0.0%	0.0%	0.5%	0.0%	0.0%	0.0%	0.0%
3.75	0.2%	0.0%	0.0%	0.0%	0.0%	1.6%	0.0%	0.0%	0.0%	0.0%
5.25	0.5%	0.0%	0.0%	0.0%	0.0%	3.8%	0.1%	0.0%	0.0%	0.0%
6.75	1.1%	0.2%	0.0%	0.0%	0.0%	6.8%	0.8%	0.0%	0.0%	0.0%
8.25	1.9%	1.1%	0.3%	0.0%	0.0%	10.9%	3.2%	0.8%	0.1%	0.0%
9.75	2.8%	2.7%	1.4%	0.7%	0.0%	14.5%	9.1%	3.5%	1.3%	0.0%
11.25	4.8%	4.6%	4.0%	3.1%	1.0%	16.0%	16.0%	10.5%	6.6%	2.2%
12.75	7.1%	7.6%	7.6%	7.0%	4.7%	14.2%	21.3%	19.1%	16.4%	9.1%
14.25	11.1%	11.4%	11.9%	11.9%	11.2%	13.0%	21.0%	24.7%	24.2%	21.4%
15.75	16.2%	17.2%	17.8%	18.1%	19.4%	9.6%	15.2%	20.7%	25.8%	27.4%
17.25	22.0%	22.2%	23.3%	24.1%	25.7%	5.6%	8.7%	12.9%	16.4%	24.0%
18.75	18.5%	18.7%	19.3%	20.1%	21.4%	2.6%	3.9%	6.1%	7.3%	12.6%
20.25	11.4%	11.7%	11.7%	12.2%	13.3%	0.8%	1.0%	1.7%	1.9%	3.2%
21.75	2.4%	2.5%	2.6%	2.8%	3.2%	0.0%	0.0%	0.0%	0.0%	0.0%
23.25	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Host Vehicle Traveling Speed **[45, 55)**										
0.75	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2.25	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
3.75	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	0.0%	0.0%	0.0%	0.0%
5.25	0.1%	0.0%	0.0%	0.0%	0.0%	0.7%	0.0%	0.0%	0.0%	0.0%
6.75	0.4%	0.0%	0.0%	0.0%	0.0%	1.9%	0.0%	0.0%	0.0%	0.0%
8.25	0.6%	0.0%	0.0%	0.0%	0.0%	4.1%	0.0%	0.0%	0.0%	0.0%
9.75	1.3%	0.2%	0.0%	0.0%	0.0%	6.6%	0.2%	0.0%	0.0%	0.0%
11.25	2.1%	0.8%	0.1%	0.0%	0.0%	9.8%	1.8%	0.1%	0.0%	0.0%
12.75	3.3%	2.3%	0.8%	0.2%	0.0%	12.7%	5.1%	1.3%	0.4%	0.0%
14.25	4.8%	4.6%	2.8%	1.5%	0.1%	14.6%	10.9%	5.1%	2.4%	0.2%
15.75	7.0%	7.0%	6.2%	4.8%	1.9%	14.0%	17.8%	10.9%	6.8%	2.6%
17.25	9.5%	9.9%	9.7%	9.6%	6.8%	11.9%	20.0%	18.8%	15.6%	8.2%
18.75	12.9%	13.6%	14.4%	14.9%	14.3%	9.9%	17.7%	23.5%	22.4%	18.4%
20.25	16.4%	17.2%	18.7%	19.6%	21.4%	6.9%	13.2%	19.5%	25.2%	27.5%
21.75	18.6%	19.4%	20.9%	22.0%	24.2%	4.0%	8.0%	12.4%	16.4%	24.6%
23.25	23.0%	25.0%	26.4%	27.4%	31.4%	2.8%	5.2%	8.2%	10.7%	18.5%
Host Vehicle Traveling Speed **55+**										
0.75	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2.25	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
3.75	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
5.25	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%
6.75	0.1%	0.0%	0.0%	0.0%	0.0%	0.3%	0.0%	0.0%	0.0%	0.0%
8.25	0.2%	0.0%	0.0%	0.0%	0.0%	0.9%	0.0%	0.0%	0.0%	0.0%
9.75	0.5%	0.0%	0.0%	0.0%	0.0%	2.2%	0.0%	0.0%	0.0%	0.0%
11.25	0.8%	0.0%	0.0%	0.0%	0.0%	3.6%	0.0%	0.0%	0.0%	0.0%
12.75	1.5%	0.1%	0.0%	0.0%	0.0%	5.9%	0.1%	0.0%	0.0%	0.0%
14.25	2.4%	0.5%	0.0%	0.0%	0.0%	8.5%	0.5%	0.1%	0.0%	0.0%
15.75	3.6%	1.7%	0.3%	0.0%	0.0%	10.5%	2.4%	0.2%	0.0%	0.0%
17.25	5.0%	3.8%	1.6%	0.5%	0.0%	12.5%	5.7%	1.6%	0.1%	0.0%
18.75	6.5%	6.6%	4.2%	2.4%	0.4%	13.6%	11.7%	4.3%	1.6%	0.0%
20.25	8.8%	9.2%	8.3%	6.6%	2.6%	11.9%	16.8%	10.4%	5.3%	0.4%
21.75	10.7%	11.4%	12.1%	11.4%	7.9%	9.9%	19.8%	18.2%	13.5%	2.6%
23.25	60.0%	66.7%	73.5%	79.2%	89.2%	20.2%	42.9%	65.2%	79.5%	97.0%

*equivalent to half of the crash impact speed
Source: SIM simulation output

Table IV-10
Derived Average Delta-V (MPH)

Host	Baseline					Treatment				
Vehicle	Remote Vehicle Travel Speed (MPH)					Remote Vehicle Travel Speed (MPH)				
Speed	**[10, 25)**	**[25, 35)**	**[35, 45)**	**[45, 55)**	**55+**	**[10, 25)**	**[25, 35)**	**[35, 45)**	**[45, 55)**	**55+**
[10, 25)	7.73	7.73	7.75	7.77	7.83	5.36	5.84	6.25	6.42	6.82
[25, 35)	12.68	12.75	12.87	12.96	13.10	8.52	9.74	10.48	10.85	11.50
[35, 45)	16.21	16.45	16.67	16.86	17.21	11.62	13.51	14.51	15.07	15.94
[45, 55)	19.41	19.93	20.33	20.57	21.05	14.97	17.63	18.85	19.53	20.52
55+	21.38	22.09	22.51	22.74	23.04	18.28	21.34	22.35	22.81	23.20

Table IV-11
Traveling Speed Distribution*

Host Vehicle	Remote Vehicle Travel Speed (MPH)				
Speed	**[10 , 25)**	**[25, 35)**	**[35, 45)**	**[45, 55)**	**55+**
[10, 25)	18.27%	16.92%	18.38%	7.40%	1.63%
[25, 35)	6.97%	5.89%	2.98%	1.90%	0.27%
[35, 45)	5.52%	1.90%	3.25%	1.08%	0.21%
[45, 55)	2.75%	0.64%	0.92%	1.40%	0.16%
55+	0.92%	0.16%	0.27%	0.05%	0.16%

*used as weight to calculate the delta-v level for an average PCP-S

Table IV-12
Delta-V for an Average PCP-M Crash

	Baseline	Treatment
Delta-V (MPH)	10.63	8.30

For IMA crashes as a whole, i.e., PCP-S and PCP-M combined, the average delta-v for an IMA crashes is the weighted average of individual delta-v for PCP-S and PCP-M. Of the IMA crashes, PCP-S comprised about 35.46 percent of the crashes and PCP-M comprised 64.54 percent of the crashes. Applying these factors to the corresponding individual delta-v shown in Tables IV-8 and IV-12 respectively derives the average delta-v for IMA crashes. For the baseline IMA crashes, the average delta-v is about 8.43 mph and 6.82 mph for a treatment IMA crash. IMA would reduce the severity of IMA crashes by an average of 1.61 mph delta-v as shown in Table IV-13.

Table IV-13
Delta-V for an Average IMA Crash

	Baseline	Treatment	Difference
Delta-V (MPH)	8.43	6.82	1.61

The average delta-v of 8.43 and 6.82 mph for the baseline and treatment IMA crashes were then input into the injury probability curves to assess the probability that a person would receive a certain level of MAIS injuries. The resulting probabilities for the baseline and treatment groups were used to estimate the reduction rate (i.e., crashworthiness effectiveness) for each of MAIS level. The following describes the injury probability curves.

A.1.3 Injury Probability Curves

Injury probability curves were derived based on a logistic model using CDS data. The logistic model predicts the probability of MAIS injuries that would occur at a specific delta-v level. The independent variable of the model, delta-v, is the reported total delta-v. The dependent variable of the model is MAIS+ injury severity which is dichotomous. The value is 0 when an injury is less than a certain MAIS level and 1 if an injury is equal to or greater than that MAIS level. Delta-v is the independent variable.

For IMA crashes, the derived MAIS+ injury probability curves for a delta-v level x have the form:

$$p_{MAIS+}(x)=\frac{e^{ax+b}}{1+e^{ax+b}}$$

Where, a = 0.076104, b = -1.54409 for MAIS1+

a = 0.13070, b = -5.59816 for MAIS2+

a = 0.14244, b = -7.63018 for MAIS3+

a = 0.12462, b = -8.46744 for MAIS4+

a = 0.12271, b = -9.45749 for MAIS5+

a = 0.12557, b = -9.75850 for fatality

The probability for certain injury level is simply the difference of two MAIS+ probabilities. In other words, $p_{MAIS1}= p_{MAIS1+}- p_{MAIS2+}$, $p_{MAIS2}= p_{MAIS2+}- p_{MAIS3+}$, and etc.

C.1.4. Crashworthiness Effectiveness by MAIS

For calculating the injury reduction Rates, the delta-vs produced for the baseline and treatment were input into the MAIS+ formula. Table IV-14 presents the process. As shown, a reduction on delta-v by 1.61 mph, IMA would mitigate MAIS 1 injuries by 8 percent, MAIS 2 injuries by 11 percent, and MAIS 4 injuries by 100 percent. Note that at the delta-v level of 8.43 and 6.82

mph levels, the probabilities of having MAIS3+ injuries are small. Therefore, the probability estimation for MAIS 3, MAIS4, MAIS 5, and fatality would have a greater variation for these injury levels than MAIS 1-2 levels.

Table IV-14
Probabilities of MAIS Injuries and Injury Reduction Effectiveness

Injury Severity	Probability		Injury Severity	Probability		Injury Reduction Rate
	Baseline (8.43 MPH)	Treatment (6.82 MPH)		Baseline (8.43 MPH)	Treatment (6.82 MPH)	
MAIS1+	0.289	0.264	MAIS1	0.278	0.255	0.08
MAIS 2+	0.011	0.009	MAIS 2	0.009	0.008	0.11
MAIS 3+	0.002	0.001	MAIS 3	0.001	0.001	0.00
MAIS 4+	0.001	0.000	MAIS 4	0.001	0.000	1.00
MAIS 5+	0.000	0.000	MAIS 5	0.000	0.000	0.00
Fatality	0.000	0.000	Fatality	0.000	0.000	0.00

Source: 2000-2013 CDS

B. Effectiveness for LTA

B.1 Crash Avoidance Effectiveness (E_a) for LTA

The analysis used the MiniSim crash results to estimate the overall system E_a for LTA. As described earlier, the crash results were based on the 96 volunteer drivers in two pre-crash scenarios:

- Left Turn Across Path, Opposite Direction, the RV continues to cross straight and the HV continues to move and turns left across the path of the other. This is scenario is abbreviated as LTA–M for moving.
- Left Turn Across Path, Opposite Direction, the RV continues to cross straight and the HV first stops and later turns left across the path of the other. This scenario is abbreviated as LTA-S for stopped.

In both scenarios, RV is traveling at 45 mph. Table IV-1 shows the MiniSim crash results and the derived E_a by crash scenario for control and treatment groups. Data from two drivers for LTA-M, one each from the control and treatment groups, were excluded from analysis due to inaccurate information. As shown in Table IV-15 below, for LTA-M crashes, the crash rate for the treatment group is 0.04 (= 1/23) and 0.17 (=4/23) for the control group. As a result, LTA would avoid 75 percent (= 1- 0.04/0.17) of LTA-M crashes, i.e., the initial E_a = 0.56 for LTA-S crashes. For the LTA-S scenario, the crash rate is 0.17 (= 4/24) for the treatment and 0.25 (= 6/24). Therefore, the LTA effectiveness against LTA-S crashes is 33 percent = (1 – 0.17/0.25), i.e., the initial E_a = 0.56 for LTA-S crashes.

Table IV-15
LTA Crash Results

	LTA-M		LTA-S	
	Treatment	Baseline	Treatment	Baseline
Crashes	1	4	4	6
No Crashes	22	19	20	18
Total	23	23	24	24
Effectiveness	75%		33%	

The single point effectiveness estimates of 33 and 75 percent shown in the above table were for one RV traveling speed at 45 mph. Without any other data to discern the effectiveness of LTA for other speeds, these estimates were applied to all other speeds. However, for the condition where the RV speeds were in the [0, 10) mph range, we were concerned that there would possibly be many false alarms and it may be not to provide an alarm in this condition. Therefore, the LTA effectiveness for crashes occurred under this condition was treated as 0. In addition, the analysis also considered an operational design that LTA would be activated when RV was traveling at least 25 mph, i.e., 25+ mph. For this design, the effectiveness is also treated as 0 for crashes where RV was traveling between [10, 25). The other design that was considered does not have this activation constraint, i.e., LTA can also issue a warning in this [10, 25) mph range. These effectiveness rates then were weighted by their corresponding crash proportion to derive the overall $E_{a.}$ When calculating the overall E_a, treating effectiveness as 0 is equivalent to excluding those portions of crashes. As a result, there were two crash proportions that were used as weight to calculate the overall E_a. The smaller proportion represents the crash distribution for 25+ mph and the larger value represents the crash distribution for 10+ mph.

Table IV-16 presents the process of deriving the overall E_a. As shown, LTA would prevent 49 - 63 percent of LTA crashes. However, according to the current design of LTA, LTA would be activated only when the left turn signal is initiated. Otherwise you would constantly be given a warning every time a vehicle approached from the other direction. Based on an SAE study by Richard Ponziani[86], about 75 percent of drivers would use the turn signal when making left turns. Therefore, the derived effectiveness at lower bound was further discounted by 25 percent to 37 percent (= 49*0.75). This serves as the lower bound of final LTA crash avoidance effectiveness. The agency believes that over time when drivers realize the benefit of LTA, drivers would be more likely to use the turn signal when turning. Therefore, 63 percent is treated as the high bound of the effectiveness. LTA would avoid **37 to 63 percent** of the LTA crashes. The wide range addresses the uncertainty for the estimate.

Table IV-16
Effectiveness for LTA-M and LTA-S

MiniSim Estimated Initial Effectiveness (E_a)

	LTA-M	LTA-S
Effectiveness	75%	33%

Percent of Crash Distribution*

	LTA-M	LTA-S
Low	57.12%	19.04%
High	73.69%	23.57%

*sum over LTA-S and LTA-M does not add up to100% because some LTA crashes do not belong to either of these conditions

Crash Avoidance Effectiveness for LTA

	Low	High
Derived	49%	63%
Final**	**37%**	**63%**

**Adjusted for turn signal use but only for lower bound

B.2.2 Crashworthiness Effectiveness for LTA

LTA is designed to assist the driver of the left turning vehicle in making a decision whether to proceed with the left-turn maneuver at the intersection. LTA is not expected to influence the movement of the RV, i.e., RV would not be alerted by LTA. Therefore, LTA is considered to

[86] Ponziani, R., "Turn Signal Usage Rate Results: A Comprehensive Field Study of 12,000 Observed Turning Vehicles," SAE Technical Paper 2012-01-0261, 2012, doi:10.4271/2012-01-0261

have no impact on mitigating the severity of the LTA crashes that cannot be avoided. Therefore, no crashworthiness effectiveness is estimated for LTA.

C. Summary of Effectiveness of IMA and LTA

Table IV-17 summarizes the estimated crash avoidance and crashworthiness effectiveness for IMA and LTA that were derived from the previous sections. Crash avoidance effectiveness was derived based on the SIM computer simulations and MiniSim driving simulator. Crashworthiness effectiveness was derived from IMA only since LTA is not expected to influence the movement of the RV and thus the resulting crash severity. As shown, IMA is estimated to prevent 43 - 56 percent of IMA crashes and LTA would prevent 37 - 63 percent of LTA crashes. Note that a wider effectiveness range is used in the uncertainty analysis to address the variations for input variables that were used in the SIM.

Table IV-17
Summary of System Effectiveness for IMA and LTA

Crash Avoidance Effectiveness (E_a)

	Low	High
IMA	43%	56%
LTA	37%	63%

Crashworthiness Effectiveness (E_w)

Injury Severity	IMA	LTA
MAIS 1	8%	NA
MAIS 2	11%	NA
MAIS 3	0%	NA
MAIS 4	100%	NA
MAIS 5	0%	NA
Fatality	0%	NA

NA: not applicable

CHAPTER V. BENEFITS

In this NPRM, the agency has decided to mandate V2V technology, but not mandate any specific apps. With specified performance requirements of DSRC devices and message transmitting protocol, the NPRM allows the implementation of interoperable V2V communication devices. Because of the cooperative nature, V2V can only function effectively when the participating vehicles can transmit the same information using the same protocol. As demonstrated in the following sections in this chapter, the benefits of V2V depend on the probability of vehicles that can communicate actually encountering each other. Therefore, a low adoption rate for a long period of time would significantly impact the V2V benefits, because the likelihood of communication-capable vehicles encountering one another would remain similarly low. Thus, V2V will be successful when a significant level of adoption can be reached. This encourages a free-market approach for apps.

However, this free-market approach to app development and deployment makes estimating the potential benefits of the proposed rule challenging. In a traditional NHTSA analysis of a safety technology, the agency would determine benefits by looking to the target population for the type of crash it is trying to avoid or mitigate and the effectiveness of the mandated performance requirements or safety technology in addressing those crashes. However, here, the technology being mandated by the agency, V2V communication, would not, on its own lead to any safety benefits. Rather, V2V would enable the development of new safety apps that would not be possible without this line of information, as well as help improve the performance of safety applications that already exist based on cameras or sensors. Further, V2V technology is expected to speed-up the deployment of various V2I technologies, which could have significant safety, congestion-relief, and mobility applications. Due to the low estimated cost of implementing apps and based on the industry's V2V development and deployment plans (publicly accounted and confidential information), the agency is confident that safety apps will be developed and deployed once V2V communications are mandated.

The below analysis calculates benefits for a scenario in which two safety apps, IMA and LTA are adopted. We have chosen these apps because the agency believes they are only possible using

V2V technology and we have conducted sufficient testing of these two apps to allow for an estimate of their potential benefits. Although there is no concrete market data to allow the agency to make definitive predictions about how or when these two apps will be implemented, the agency believes it has developed a plausible app adoption scenario based on several sources including an interviewed survey conducted on the future V2V market, NCAP data related to deployment of vehicle-resident advanced technologies, and other information obtained by the agency. Furthermore, by focusing on only two of the many potential uses of V2V technology, the agency has taken a reasonable approach in quantifying the potential benefits of the proposed rule. Potential benefits for other apps such as FCW and BSW/LCW[87] were not considered because the effectiveness of these apps could be achieved by vehicle-resident systems. The non-quantified impacts section at the end of this chapter will discuss these benefits. The agency will continue to monitor the app adoption after the rule is finalized.

Benefits are presented in two measures: annual benefits and the lifetime benefits for a model year vehicles (MY benefits). The annual benefits represent the collective benefits that would be accrued from all V2V-equipped vehicles for a specific calendar year. The MY benefits represent the total benefits that would be realized through the life of a MY vehicles. The MY benefits thus are required to be discounted by 3 and 7 percent to reflect their present value. The annual benefits will also be discounted later in the breakeven analysis to determine the year that the total costs of the proposed rule will be paid back through the total realized benefits of the proposed rule. The MY benefits will be used in the cost-effectiveness and net-benefit analyses respectively to determine the MY vehicles that would become cost-effective and achieve positive net benefits.

Benefits include crashes, fatalities, injuries, and PDOVs (vehicles that only incur property damage and none of their occupants incur an injury) that can be reduced by the proposed rule. Generally, benefits of a vehicle safety countermeasure are influenced by the size of the crash population (or target population) that would be impacted by this technology and the effectiveness

[87] These technologies were tested in the safety pilot deployment.

of the technology. For V2V-based safety systems (i.e., apps), the activation of these systems would depend on the communication probability among vehicles. Therefore, there are three major factors that would influence the benefits: the size of the crash population, app effectiveness, and vehicle communication rates. The undiscounted annual benefits thus are the product of these three factors and can be expressed mathematically by the following generic formula:

$$B_i = P * E * C_i$$

Where, B_i = Annual benefits (or MY benefits) of the proposed rule at year i,

P = Target population (crashes, fatalities, injuries, or PDOVs),

E = Effectiveness of apps (i.e., IMA or LTA), and

C_i = communication rate at year i.

A. Target Population (P)

The target population (P) includes crashes, fatalities, injuries, and property damaged only vehicles (PDOV, vehicles that only incur property damage and none of their occupants incur an injury) that are expected to be impacted by IMA and LTA. These target populations were retrieved from the 2010-2013 FARS and GES. FARS is a census of fatalities that occurred in fatal crashes on public roadways. FARS was used to derive the incidence of fatal target crashes and associated fatalities. GES is a sampling system of all police-reported crashes. GES was used to derive the MAIS 1+ injuries in non-fatal target crashes and PDOVs. The purpose of using multiple years of crash data was to limit variations of estimated number of crashes that might occur using only one year of sample data. Variables that were used to define the target crashes include vehicle forms submitted, vehicle body type, crash type, the first harmful event, relation to roadway, roadway alignment, roadway condition, rollover type, jackknife status, driver contributing factor, and vehicle contributing factor. Of these variables, the driver contributing and vehicle contributing factors were used to refine the target population. The driver contribution factor specifies whether driver's alertness contributed to the crashes. The vehicle contributing factor identifies whether vehicle's component failure or defect contributed to the crashes. Crashes where incapacitated or drowsy drivers were involved and where vehicle mechanical failures such as brake systems, tires, steering, and transmissions were cited as contributing factors were excluded.

As shown in Figure I-1 in the Introduction chapter, the proposed rule could affect 3.4 million LV2LV crashes that potentially can be affected by the proposed rule. Other crashes were excluded from the analysis for various reasons. Single-vehicle crashes were excluded since the V2V technology is based on two vehicles communicating with each other before a crash. Crashes with four or more vehicles were not included because we are not certain how effective the apps would be as these crashes might involve complicated interactions among vehicles. Crashes involving pedestrians and pedal-cyclists were excluded since these crashes might need the communication between vehicles and persons. Crashes involving motorcycles were excluded because the agency has not conducted any V2V research on motorcycles. Finally, crashes involving at least one heavy vehicle[88] are excluded since the agency is only evaluating light vehicle crashes at this time.

A.1 Baseline Target Population

For the 3.4 million crashes that can be affected by the proposed rule, the agency was able to quantify the benefits for crashes that can be prevented by IMA and LTA (two V2V exclusive apps). Benefits for other apps (i.e., FCW, BSW/LCW, DNPW, and EEBS) that were deployed in the Safety Pilot Model Deployment were not quantified for various reasons.[89] Crashes that would be affected by IMA (i.e., IMA crashes) are intersection crashes where vehicles were straight cross passing or where a vehicle turned into the same direction or opposite direction of another vehicle's path. Crashes that would be affected by LTA (i.e., LTA crashes) are those intersection crashes when a vehicle is making a left turn across the path of the other vehicle that is traveling straight from the opposite direction. Intersection crashes included intersection (signalized and non-signalized), intersection-related, driveway/alley, and driveway access related crashes. The DSRC equipped vehicle doesn't know if there is a red light, a stop sign, or even if there is a street there, but it can determine that if both vehicles continue at their present heading and speed that a crash will occur. Figure V-1 depicts the IMA and LTA crash diagrams that are

[88] Heavy vehicles include trucks and buses with a GVWR greater than 10,000 pounds.

[89] Please see the discussion on "Non-Quantified Benefits" for details.

based on the crash type categorization and coding scheme in the GES and FARS manuals. IMA is represented by six different crash types. LTA is represented by only one crash type.

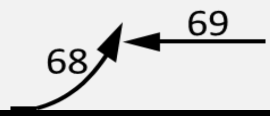
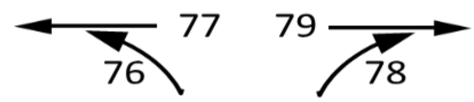
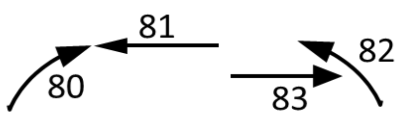
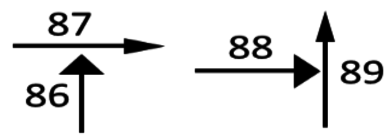
LTA **Change Trafficway - Turn Across Path** **Initial Opposite Direction** **(Crash Type: 68/69)**[90]	**IMA** **Change Trafficway - Turn Into Path** **Turn Into Same Direction** **(Crash Type: 76/77, 78/79)**
	
IMA Change Trafficway -Turn Into Path Turn Into Opposite Direction **(Crash Type: 80/81, 82/83)**	**IMA** Intersect Paths -Straight Paths**(Crash Type: 86/87, 88/89)**
	

Figure V-1
Crash Type Schemas for IMA and LTA

Figure V-2 depicts the process to determine the final target population for the apps (i.e., IMA and LTA) and the corresponding monetized values. As shown, there are 1.06 million IMA and LTA crashes. When combined, they are about 19 percent of the total police-reported crashes. These crashes resulted in 2,372 fatalities and 0.69 million MAIS 1-5 injuries and damaged 1.29 million vehicles. Together, these crashes cost society $121 billion, annually. Separately, IMA crashes resulted in 1,824 fatalities and 0.47 million MAIS 1-5 injuries and damaged 0.97 million vehicles. The IMA crashes cost society $84 billion, annually. When compared to IMA, LTA has a smaller number of target crashes. LTA crashes resulted in 548 fatalities and 0.22 million injuries (MAIS 1-5) and damaged 0.32 million vehicles. The IMA crashes cost society $36 billion, annually. For each of the cited categories (crashes, injuries, fatalities, PDOVs, or societal costs), the IMA annual estimates are 2.1 to 3.3 times more than the corresponding LTA

[90] The identification numbers used in the GES PARs.

annual estimates. For example, 0.47 million injuries for IMA/0.22 million injuries for LTA = 2.1 and 1,824 fatalities for IMA/548 fatalities for LTA = 3.3.

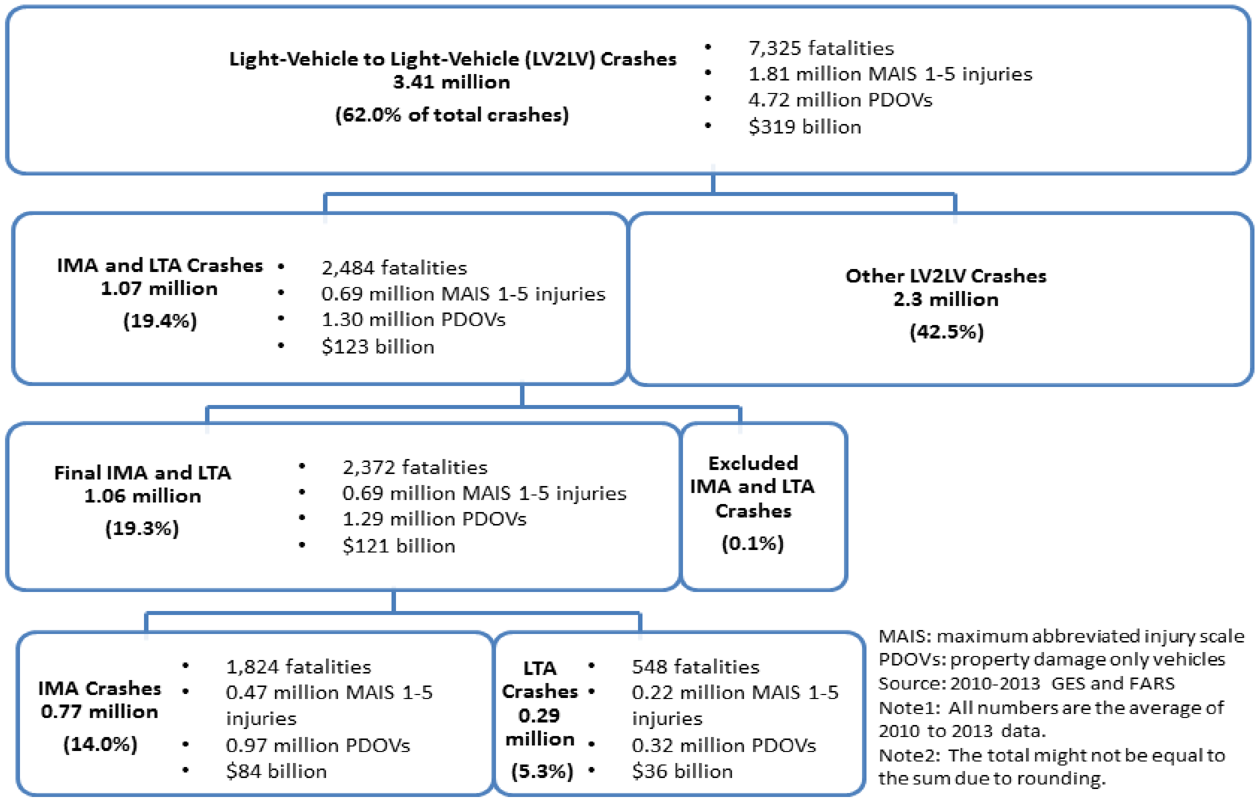


Figure V-2
Annual LV2LV Crash Population Breakdown

The categorization of IMA and LTA crashes (and other crash types such as FCW crashes) was generally based on the 37 pre-crash topologies that were developed by VOLPE.[91,92] The IMA crashes as defined in the PRIA included these crashes from the 37 crash topologies: 16 Vehicle Turning on Same Direction, 28 Vehicle Turn Right at Signalized Junction, and 31 Vehicle Turning at Non-Signalized Junction. The LTA crashes included 27 Left Turn Across Path from

[91] Frequency of Target Crashes for Intellidrive Safety Systems (Najm, Koopman, Smith, and Brewer, October 2010, Report No. DOT HS 811 381). See www.nhtsa.gov/Research/Crash+Avoidance/ci.Office+of+Crash+Avoidance+Research+Technical+Publications.print (last accessed Jan. 30, 2014).

[92] Analysis of Light Vehicle Crashes and Pre-Crash Scenarios Based on the 2000 General Estimates System (Najm, Sen, Smith, and Campbell, Nov. 2002, Report No. DOT HS 809 573). See www.nhtsa.gov/Research/Crash+Avoidance/ci.Office+of+Crash+Avoidance+Research+Technical+Publications.print (last accessed Jan. 9, 2014).

Opposite Direction at Signalized Junction and 29 Left Turn Across Path from Opposite Direction at Non-Signalized Junction.

For consideration of the operational app effectiveness, some of IMA and LTA crashes were excluded from the analysis. These crashes are labeled as "excluded IMA and LTA crashes" in the PRIA. The excluded IMA and LTA crashes are crashes where an involved vehicle had one of these conditions: driver alcohol involvement, vehicle failure (tire, engine, and other disabling failure), and lost control (skidding or jackknifing). For IMA crashes, we excluded any IMA crash when both vehicles involved in the crash had one of the above conditions. In contrast, we excluded LTA crashes where the left-turning vehicle had one of the conditions. The agency assumes that the driver would not have an effective response to warnings for these crash conditions.

Table V-1 provides the detailed MAIS injury statistics for the final IMA and LTA crashes. Since IMA and LTA can be effectively enabled only by V2V, we assumed that no vehicle-resident version of these two apps would impact the IMA and LTA crashes. Therefore, IMA and LTA crashes derived from 2010 - 2013 GES and FARS were used as the target population at the 2021 level for benefit estimates.

Table V-1
Baseline IMA and LTA Crashes

	IMA	LTA	IMA & LTA TOTAL
Crashes	770,747	291,651	1,062,398
Fatality	1,824	548	2,372
MAIS 1	417,660	191,880	609,540
MAIS 2	38,782	19,133	57,915
MAIS 3	10,399	5,257	15,656
MAIS 4	2,050	1,048	3,098
MAIS 5	749	355	1,104
MAIS 1-5	469,640	217,673	687,313
PDOVs	974,496	318,475	1,292,971

Source: 2010-2013 GES and FARS

MAIS represents the maximum injury severity of an occupant at an Abbreviated Injury Scale (AIS) level.[93] However, GES and FARS record only the police-reported KABCO[94] injuries, not MAIS (maximum AIS). Table V-2 shows the initial annualized KABCO injures for all crashes, LV2LV crashes, and the target IMA and LTA crashes (IMA and LTA crashes in short).

Table V-2
Annualized Police-Reported KABCO injuries

Crash Type	K	A	B	C	O	U
All Crashes	33,020	172,569	657,450	1,373,106	11,071,896	79,639
LV2LV	6,254	71,207	348,331	998,451	8,332,128	51,065
IMA	1,824	22,961	114,638	259,676	1,785,209	13,449
LTA	548	11,609	61,935	128,459	638,654	4,841

Source: 2010-2013 GES and FARS

After deriving the KABCO injuries, these KABCO injuries were translated into AIS injuries through a KABCO-AIS conversion table. This conversion allows the use of the AIS-based crash unit costs that were developed by the agency to estimate the monetized benefits. The KABCO-AIS conversion table was established using two data systems: 2000 – 2008 Crashworthiness Data Systems (CDS) and 1982 – 1986 National Accident Sampling System (Old NASS). CDS is a sample system of passenger vehicle crashes in which at least one passenger vehicle was towed away from the crash site. CDS collects injury information only for passenger vehicle occupants in a more severe crash environment (i.e., at least one passenger vehicle was towed). Therefore, a KABCO-to-AIS translation table derived solely from CDS might not be representative of the overall injury outcomes especially for less severe crashes. The Old NASS data, on the other hand, were a nationally representative sample of all crashes of all vehicle types on public roadways. However, as the name indicated, the Old NASS system is a relatively ancient crash database. The crash environment and vehicle technologies have changed since 1986, the last year of the Old NASS system. Further, the AIS system was revised several times (1995, 1998, and 2005)[95] to take into account the improvement of emergency response and advancement of medical technologies. A conversion table derived solely from the Old NASS thus might not

[93] AIS ranks individual injuries by body region on a scale of 1 to 6: 1=minor, 2=moderate, 3=serious, 4=severe, 5=critical, and 6=maximum (untreatable).

[94] K: fatality, A: incapacitated injury, B: non-incapacitating injury, C: possible injury, O: no -injury

[95] The 1995 version is implemented in the current CDS up to 2009.

appropriately reflect the current injury outcomes. In order to balance the representation of crash sample, sample size, and the reflection of AIS coding updates, non-CDS types of crashes from Old NASS were combined with CDS incidents to generate the conversion table. The 2009 and newer CDS were not incorporated to derive the conversion table due to the data collection policy which did not record injury information for occupants in vehicles older than 10 years. The translated AIS injuries are assumed to be the MAIS for associated occupants. Table V-3 shows the KABCO-to-MAIS conversion table. Since the police-reported fatal injuries (K) were derived from FARS, a census of fatalities, all K injuries were attributed to fatalities in MAIS system. Applying the KABCO-to-MAIS conversion factors (Table V-3) to corresponding KABCO injuries (Table V-2) derives the MAIS injuries as shown in Table V-1 above (Figure V-2 also).

Table V-3

KABCO-to-MAIS Conversion Table

	Police-Reported Injury Severity System					
	O	C	B	A	K	U
MAIS	No Injury	Possible Injury	Non Incapacita-ting	Incapacita-ting	Fatality	Injured, Severity Unknown
0	0.92535	0.23431	0.08336	0.03421	0.00000	0.21528
1	0.07257	0.68929	0.76745	0.55195	0.00000	0.62699
2	0.00198	0.06389	0.10884	0.20812	0.00000	0.10395
3	0.00008	0.01071	0.03187	0.14371	0.00000	0.03856
4	0.00000	0.00142	0.00619	0.03968	0.00000	0.00442
5	0.00003	0.00013	0.00101	0.01775	0.00000	0.01034
Killed	0.00000	0.00025	0.00128	0.00458	1.00000	0.00046
Total	1.00001	1.00000	1.00000	1.00000	1.00000	1.00000

Source: 1982-1986 Old NASS; 2000-2008 CDS

The monetized values for crashes shown in Table V-4 are comprehensive costs. Comprehensive costs include economic costs and the value of quality of life (QALYs). Economic costs reflect the tangible costs of reducing fatalities and injuries include savings from medical care, emergency services, insurance administration, workplace costs, legal costs, congestion and property damage, as well as lost productivity. Congestion costs included travel delay, added fuel usage, and adverse environmental impacts cost. The environment impacts included the estimated reduction of greenhouse gas and pollutant emissions due to vehicle delay hours and added fuel consumption that resulted from congestion caused by crashes. Crashes not only result in vehicle delay hours but also in wasted fuel, increased greenhouse gas production, and increased criteria pollutant emissions as engines idle while drivers are caught in traffic jams and slowdowns. These impacts are also created when drivers are forced to detour around a crash. Such detours can be a matter of blocks or miles, but in either case, more fuel is burned by other motorists as a direct result of the initial crash. The QALY captures the intangible value of lost quality-of-life that results from these fatalities and injuries. The comprehensive unit costs are expressed on a per-person basis for all MAIS injury levels and per vehicle for PDOVs. The agency periodically updates these unit costs for the above cost components and estimate the total crashes costs to society. The latest crash cost update in 2010 economic value was completed on May 2015.[96] These unit costs were further revised to the 2014 value by applying appropriate Consumer Price Indexes (as of March 28, 2015) to the corresponding cost components and by following the 2015 DOT guidance on value of statistical life (VSL) value and the treatment of VSL.[97] VSL reflects the aggregation of individuals' willingness to pay for fatal risk reduction and would directly impact the value of QALY. The 2015 guidance established $9.2 million for the VSL in 2013 dollar. The value becomes $9.4 million when expressed in 2014 dollars. Included in the VSL are QALYs, Household Productivity, and the taxes portion of the Market Productivity. Table V-4 shows the unit costs of police-reported crashes. The comprehensive unit costs are the sum of all the components. These unit costs will also be used to estimate the monetized benefits of the proposed rule.

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[96] Blincoe, L. J., Miller, T. R., Zaloshnja, E., & Lawrence, B. A. (2015, May). The economic and societal impact of motor vehicle crashes, 2010. (Revised) (Report No. DOT HS 812 013). Washington, DC: National Highway Traffic Safety Administration

[97] For more information, please see a 2015 Office of the Secretary memorandum on the "Guidance on Treatment of the Economic Value of a Statistical Life in U.S. Department of Transportation Analyses." http://www.dot.gov/regulations/economic-values-used-in-analysis.

Table V-4
Unit Costs of Police-Reported Crashes
(2014 dollars**)**

	PDOVs	MAIS 0	MAIS1	MAIS2	MAIS3	MAIS4	MAIS5	Fatal
Medical	$0	$0	$3,137	$12,835	$54,485	$152,761	$430,627	$12,682
EMS	$64	$41	$118	$240	$452	$910	$928	$979
Market Productivity	$0	$0	$2,955	$20,982	$69,733	$152,623	$365,915	$1,011,514
Household Productivity	$65	$49	$934	$7,702	$24,590	$40,689	$103,407	$314,218
Insurance. Adm.	$207	$155	$3,580	$5,058	$16,688	$30,646	$78,737	$30,748
Workplace	$67	$50	$370	$2,866	$6,260	$6,894	$12,021	$12,771
Legal	$0	$0	$1,283	$3,638	$13,464	$28,952	$89,795	$115,609
Travel Delay	$2,280	$1,535	$1,545	$1,572	$1,615	$1,638	$1,657	$6,200
QALYs	$0	$0	$24,581	$385,107	$860,345	$2,179,542	$4,858,903	$8,193,766
Property Damage	$3,908	$2,923	$8,641	$9,239	$17,400	$17,727	$16,385	$12,172
Comprehensive - Crash Avoidance Total	$6,591	$4,753	$47,144	$449,239	$1,065,032	$2,612,382	$5,958,375	$9,710,659

A.2 The Potential Impact of Advanced Safety Technologies on Baseline Target Population

In constructing the baseline target population for this analysis, we assumed that average annual fatalities will remain flat for the future period of time covered by the analysis. This reflects uncertainty as to how unknown technology changes and future efforts to improve vehicle safety will interact with the expected growth in travel, which will increase exposure to risk. However, the unique nature of V2V has caused the agency to consider additional approaches to how the baseline could be constructed. That is, for nearly all other vehicle-resident safety technologies (including advanced safety technologies) benefits begin accruing to the vehicles installed with them immediately. By contrast, as discussed throughout the NPRM and this analysis, V2V is different because it requires interactions with other V2V-equipped vehicles in order for benefits to accrue. This implies that given the same penetration rates, safety target population, and effectiveness, V2V benefits will accrue smaller than vehicle-resident safety technologies during the period of analysis of the proposed rule. The agency recognizes that the potential development of automated vehicles and other automated safety technologies could revolutionize vehicle safety by the time the full fleet of vehicles on the road is equipped with V2V. We have examined possible outcomes under some optimistic far-future assumptions.

As an initial point, we believe that our existing baseline, which is derived from average incidence from the 2010-2013 period, is conservative. First, this timeframe reflects historically low levels of traffic fatalities. While the much of the recent decline in fatalities is due to improved vehicle safety, some portion reflects the impact of the 2008 recession and the slow recovery period following it on economic activity and travel. However, using the fatalities as an example, results from 2014 and 2015 FARS indicate that fatalities are increasing as the economic recovery proceeds as depicted in Figure V-3, history of motor vehicle fatalities.

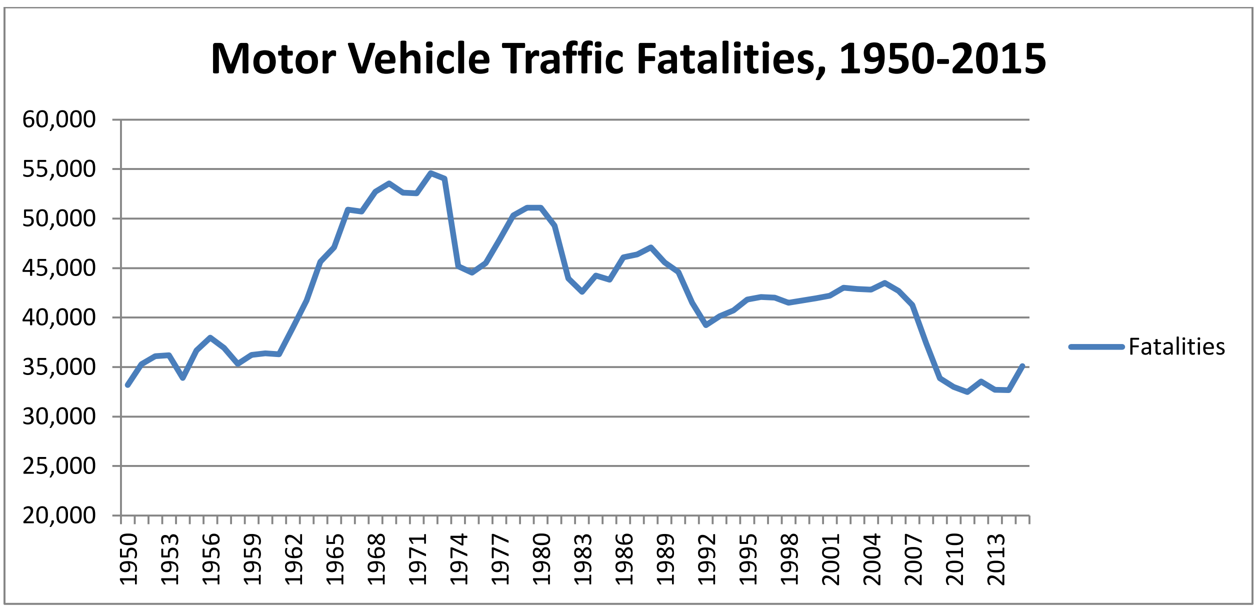


Figure V-3
History of Motor Vehicle Fatalities

Second, our benefits analysis only looks at the potential benefits of two safety applications: LTA and IMA. We chose those technologies specifically because, based our analysis of existing advanced vehicle-resident technologies, we believe that V2V is necessary for those applications to function. We have not included all other potential uses of V2V that would enhance or even replace vehicle-resident technologies. We chose to do this to avoid speculation regarding the degree of overlap between vehicle-resident and V2V based solutions, but there are potentially significant benefits that could be derived from V2V in other crash modes as well.

Third, by adopting a "constant" baseline going forward, we are implicitly assuming reduction in effective crash/death/injury rates (whether due to automation or some other cause) because vehicle miles travelled (VMT) are projected to increase significantly over time. VMT is the standard measure for estimating the risk of crash/fatality/injury involvements because it represents exposure to risk. Increasing VMT (i.e., exposure) increases risk. Added risk implies that, unless there are additional improvements in safety, fatalities will increase proportionately. By not increasing our baseline to reflect this added risk, we are implicitly assuming a level of safety improvement sufficient to offset this added exposure to risk. If future technologies develop with a combined pace of adoption and effectiveness that exceeds the growth in VMT, it would result in a reduction in our baseline target population. However, if technology growth falls short of the growth in VMT, this would increase our baseline target population.

Figure V-4 illustrates this using two different VMT projections (20 and 30 years) developed by the VOLPE center for FHWA and used in developing NHTSA's most recent CAFE standards.[98] These estimates are based on models that reflect projected population growth, economic activity, gasoline prices, projected improvements in fuel economy, and other factors that affect VMT. The "constant baseline" in Figure V-4 represents the unchanged baseline, which assumes that future potential safety improvements would offset the increase of crash risk due to VMT increase. The unchanged baseline thus will be equal to the annual average of crashes, injuries, and fatalities from 2010 to 2013. As shown, the 20 and 30 year forecast lines represent a simple projection of the average growth rates resulting from two different scenarios examined in the VOLPE VMT analysis. The 20 year forecast projects gradual VMT growth that would result in 46 percent more risk exposure 40 years in the future. The 30 year forecast projects VMT growth that would result in 28 percent more risk exposure after 40 years. In other words, the baseline could potentially increase 46 percent in the absent of any other safety improvements under the 20

[98] FHWA Forecasts of Vehicle Miles Traveled (VMT): Spring 2016
http://www.fhwa.dot.gov/policyinformation/tables/vmt/vmt_forecast_sum.cfm

year forecast and 28 percent under the 30 year projections. The 30 year forecast is based on modeling that examined conditions farther into the future, but is also more uncertain.

We show this range to illustrate the concept, but we do not advocate that either forecast is more likely. Whatever level of growth actually occurs, the difference between the flat baseline and the VMT growth line represents implicit crash/injury/fatality reduction rates due to unspecified future safety improvements. Going forward, these are likely to include some form of advanced automated vehicle technologies. As noted above, the currently available advanced safety technologies are not adequate at preventing the IMA and LTA crashes which formed our target baseline safety population. It is uncertain when better technologies might be developed, or how effective they might be in addressing these two crash types. It is possible that these crashes may not be significantly addressed by in-vehicle technologies unless/until vehicles become fully automated.

To put this in perspective, consider that it takes 35-40 years to replace the on-road fleet with new vehicles. This means that if a technology is standard in 100 percent of a new model year's fleet, after 35-40 years it will be in 100 percent of the on-road fleet as well. However, if a technology is adopted into only some portion of the new model fleet, this replacement process will be much slower, and unless it is eventually adopted into all new vehicles, it will never be in the entire on-road fleet. In addition, safety technologies typically mitigate, but do not eliminate crashes. Thus, even if a safety technology was in 100 percent of the on-road fleet, if it was, for example, 25 percent effective, it would reduce fatalities by 25 percent, leaving 75 percent of the target population still in place to be addressed by other countermeasures. Thus, to achieve the implicit safety benefits that would match either of the two scenarios noted in Figure V-4 solely based upon the advanced technologies would require a fairly aggressive adoption schedule and/or very effective technology. For example, it would be the equivalent of a gradual adoption of a technology that was either 28 percent or 46 percent effective (depending on the VMT projection) at a pace that put it in 100 percent of the on-road fleet 40 years in the future. To do this, this technology would have to be installed in roughly 100 percent of all new model vehicles today, which is clearly not possible since effective automated intersection crash avoidance technologies are still in the early stages of development. Nor, even if it were perfected today, would it be likely since the pace at which new technologies are adopted is usually quite gradual, at least in its early years of deployment.

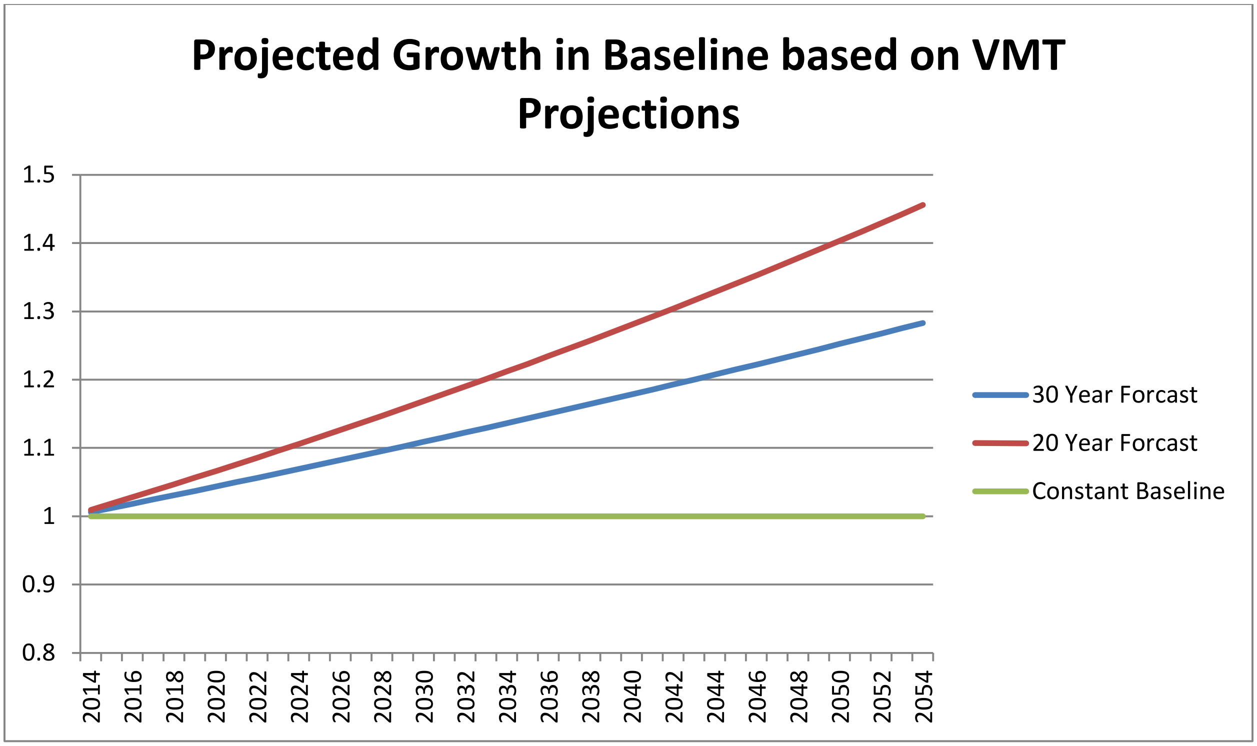
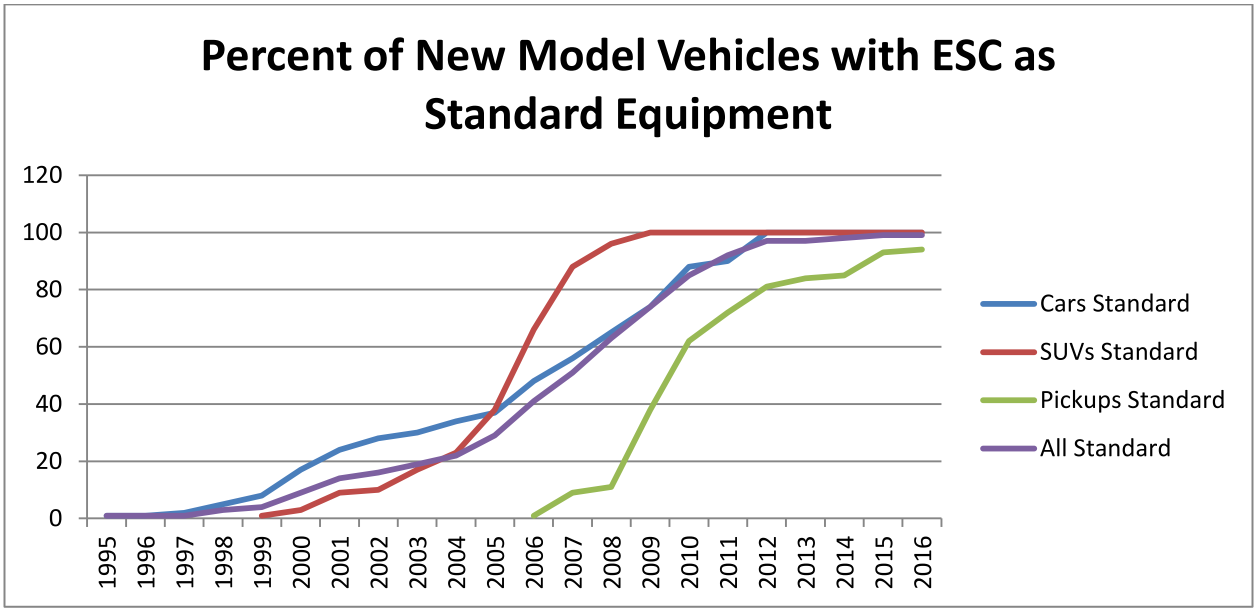


Figure V-4
Projected VMT Growth from 2014 to 2054

Typically, when new safety technologies are developed it takes time to research and perfect them. Once they are developed sufficiently, they are usually marketed first in luxury vehicles, and then they are gradually offered in other vehicle classes over time. In some cases, they may eventually be adopted as required safety equipment under an FMVSS. A good example of this is electronic stability control (ESC). ESC was first marketed in 1995 on a small number of luxury vehicles. Over time it proved to be very effective in preventing rollover crashes and was voluntarily installed on a significant number of vehicles. In particular, manufacturers recognized its importance as a safety feature on SUVs, which were particularly prone to rollover crashes and they accelerated installations into these vehicles at a rapid pace. NHTSA published an NPRM proposing to require ESC in all light vehicles in 2006. By 2007, 88 percent of SUVs and over half of all vehicles came equipped with ESC as standard equipment. ESC was then required by

FMVSS No. 126 to be installed on all light vehicles by model year 2012. Roughly 20 years after it was first marketed, ESC was standard equipment in nearly 100 percent of all new vehicles. However, it will be many more years before it is in 100 percent of the on-road vehicle fleet. Figure V-5 shows the historical installation of ESC as standard equipment.



Source: IIHS HLDI Highway Safety Research and Communications, ESC and side airbag availability by make and model. http://www.iihs.org/iihs/ratings/safety-features

Figure V-5
ESC Adoption by Vehicle Type

However, technology adoption rates can vary. ESC was adopted relatively quickly because it was recognized as an extremely effective and highly cost-beneficial technology. Thus, as technologies become more advanced beyond what currently exists in the market, any analysis of their potential adoption rate becomes increasingly speculative. For example, fully automated (level 4) vehicles may have the most potential to address our V2V target population, and a full fleet of this type of vehicles would potentially have the best chance to avoid the crashes that are caused by driver failures in intersection crashes.[99] However, full vehicle automation differs in several critical ways from the safety enhancing automated vehicle capabilities like ESC or automatic braking. First, it removes control of the vehicle from drivers, which presents significantly greater technological challenges and may face resistance in some portions of the driving public, making full adoption, even once the technology is mature, difficult. Second, fully automated vehicles will cost significantly more than traditional vehicles. They will need, in addition to the hardware and software that controls their decision-making, an entire array of sensors and/or cameras able to detect conditions from all directions and redundant mechanical systems that don't exist on current vehicles. A motor will now be needed to steer, and a separate motor will be needed to brake. Current estimates are that these implementations will initially likely add up to $100,000.[100] Even if production efficiencies were to eventually cut this cost dramatically, higher prices are certain to have some impact on market adoption rates as well. It is also possible that deployment strategies of automated vehicles could greatly affect how quickly they are deployed, since at least some of the companies researching automated vehicles appear likely to not offer them for private sale, but only use them, at least initially, as on-demand taxi services. This could increase their VMT without significantly increasing their ownership, making predicting their potential deployment even more complicated. Thus, it is not possible to determine with any level of certainty whether the current relatively inexpensive, partially automated systems are a reasonable indicator of the pace of adoption for fully automated driverless systems that could significantly increase the price of a vehicle.

[99] We note that Level 3 automated vehicles could also potentially address intersection crashes, but that would depend on whether those vehicles would be automated in the driving scenarios that include intersections. That is, a vehicle that only is automated in highway driving would not likely be automated in areas with intersections. However, a level 3 vehicle that is capable of being automated in more diverse roads (and, for example, is level 3 because of geographic restrictions, not road-type) could address intersection crashes. Due to this inherent variability, we have focused on level 4, but, by analyzing relatively aggressive adoption schedules, we think we implicitly build in the potential for some level 3 vehicles to address intersection crashes.

[100] eTRANS Systems, Driverless Transportation http://www.driverlesstransportation.com/infographic-uk-view-driverless-cars-13730 as of 8/12/16. Note that another company, IHS Markit has published estimated incremental costs for the electronics portion of self-driving cars. IHS states: "The price premium for the SDC electronics technology will add between $7,000 and $10,000 to a car's sticker price in 2025, a figure that will drop to around $5,000 in 2030 and about $3,000 in 2035 when no driver controls are available." http://press.ihs.com/press-release/automotive/self-driving-cars-moving-industrys-drivers-seat. This is sometimes mis-quoted as an estimate for all changes required to make a vehicle autonomous.

That said, there is, of course, historical evidence that fatalities can, decline even as VMT increases as illustrated in Figure V-3, the history of motor vehicle fatalities since 1950. VMT increased steadily over this time period. From 1950 through 1972 fatalities increased significantly with this increased travel. During this time frame, there were no concerted efforts to improve vehicle safety. In the early 1970s safety became a priority with the formation of NHTSA in 1970 and the initial adoption of Federal Motor Vehicle Safety Standards. Over the past decades, fatalities have declined in spite of rising VMT due to significant improvements in both vehicle crashworthiness and driver behavior. A large part of this is due to behavioral programs which have reduced the incidence of impaired driving and increased seat belt use rates. Seat belt use was below 10 percent in the earlier years and was only 14 percent in 1983. Since then it has climbed steadily to 89 percent, saving thousands of lives. Impaired driving has also declined, accounting for 48 percent of all fatalities in 1983 to 30 percent in 2014. Motor vehicle safety improvements have also had a substantial impact on traffic safety. Kahane[101] estimates that vehicle safety technologies, including increased belt use, saved over 600,000 lives between 1960 and 2012. They are currently saving roughly 30,000 lives annually. Without these combined safety improvements, the trend in motor vehicle fatalities would look very different. Previously, the primary vehicle-based source of these reductions was crashworthiness technologies that protect occupants in the event of a crash. This includes the significant increase in seat belt use from below 10 percent to nearly 90 percent use levels. However, achieving additional safety through crashworthiness technologies will become increasingly difficult since the "low hanging fruit" is already picked. Vehicles already include multiple air bags and increasing belt use will become more difficult because the last non-users are the least safety conscious drivers. Declines in impaired driving are likely to run into similar difficulties, although the agency and industry are continuing research on DADDS technologies. Thus, future improvements in safety are likely to depend primarily on crash avoidance technologies.

[101] Kahane, C. J. (2015, January). *Lives saved by vehicle safety technologies and associated Federal Motor Vehicle Safety Standards, 1960 to 2012 – Passenger cars and LTVs – With reviews of 26 FMVSS and the effectiveness of their associated safety technologies in reducing fatalities, injuries, and crashes.* (Report No. DOT HS 812 069). Washington, DC: National Highway Traffic Safety Administration.

Many crash avoidance technologies have steadily been mandated or voluntarily implemented in vehicles. Examples of these technologies include ESC, forward collision warning, advanced brake assist, backover warning, and blind spot detection. Although these technologies are effective in preventing crashes and reducing associated fatalities and injuries, these technologies cannot address the complex IMA and LAT crashes. Therefore, although overall crashes and fatalities might benefit from these technologies and possibly even decline despite VMT increases, the IMA and LAT crashes and associated fatalities and injuries that provide our baseline would likely not be affected and would, therefore, likely increase with VMT.

Figure V-6 This history shows, though, that attempting to isolate the potential benefits of market-driven safety technologies is extremely difficult, as many advances in safety have been caused by mandatory safety technologies, as well changes in state laws (particularly regarding belt usage and impaired driving) and general cultural shifts on these and other issues. Further, fatalities increased slightly from 1992 through 2005, before declining rapidly during the recession of 2007. The hope, then, shared by the agency, industry, and the general public is that advanced technologies (which we note here include those that rely or otherwise use V2V) will bend the curve in way that was done in the 1980's. However, attempting to predict what this will be with any level of certainty is not currently possible.

In order, then, to attempt to simulate potential advancements in automotive safety which might occur during the relatively long time period it would take for V2V to significantly penetrate the light-duty fleet as a result of this proposed rulemaking, the agency has made high-level speculative assumptions about the development and deployment of advanced vehicle technologies. Our initial assumption is that level 4 automated vehicles are the most likely technology that could address the intersection crashes that form the target population of this rulemaking. We note that Level 3 automated vehicles could also potentially address intersection crashes, but that would depend on whether those vehicles would be automated in the driving scenarios that include intersections. That is, a vehicle that only is automated in highway driving would not likely have an impact, but a vehicle that is capable of being automated in more diverse roads (but is level 3 because of geographic restrictions) could address intersection crashes. Due to the uncertainties as to where Level 3 vehicles will be able to operate, we have focused on

Level 4. Further, there is the potential that lower-level advanced technologies could also address intersection crashes if there is sufficient development in vehicle-resident sensors and software that would allow the sensors to detect vehicles that they currently cannot. However, given the current state of technology, speculating about those technologies contains similar, although perhaps somewhat lower, levels of uncertainty than for automated vehicles with less potential benefit. In any event, both of the below hypothetical adoption rates are considerably optimistic about the deployment rate and effectiveness of level 4 highly automated vehicles and, thus, these assumptions can be viewed as implicitly including the potential for less-advanced technologies to also have an impact on the target population.

The impact of advanced technologies analysis used two hypothetical technology adoption scenarios for highly automated vehicles to demonstrate the process of isolating their impact on the benefits of this proposed rule. These two adoption scenarios are labeled as Hypothesis 1 and Hypothesis 2 hereafter. Table V-5 shows these rates and Figure V-7 is the graphic visualization of these rates. As shown in Figure V-7, Hypothesis 1 is the less aggressive one between the two scenarios. As mentioned above, the technologies that would most likely to impact the V2V baseline are fully automated vehicles. The rate of deployment of these vehicles will likely vary based on potential cost, Federal/State/Local laws, insurance, and customer acceptance issues. The projection for fully autonomous vehicles are for those that can drive themselves on all roadway and environment conditions without human input and the automated feature cannot be manually switched off. Several companies (BMW, Ford, and Uber) have all recently announced that fully autonomous cars will be ready to drive themselves by 2021. However, these most likely will be in a very small fleet and limited to small and controlled areas (for example, van-like buses travelling around a small city lower than 10 mph) and low-speed taxi service limited to certain roads or driving in a so called “fence” corridor).[102] Due to this low-level of early deployment, these vehicles would not have a noticeable impact on the baseline. Therefore, the adoption pace for full autonomous vehicles is expected to be negligible before 2021 and is here

[102] Simonite, T, Prepare to be Underwhelmed by 2021’s Autonomous Cars, MIT Technology Review, August 23, 1016

assumed to gradually increase first within upper-priced luxury cars.[103] Under Hypothesis 1, the first noticeable adoption (1 percent or greater) occurs on MY 2025 vehicles. The adoption rate would gradually increase to over 75 percent on MY 2041 vehicles and to 100 percent for MY 2050 and newer vehicles. In contrast, for Hypothetical 2, one percent of MY 2021 vehicles would have the technology, four MY earlier than Hypothesis 1. The adoption would reach 75 percent for MY 2035 and 100 percent for MY 2045, four to five MYs earlier than Hypothesis 1.

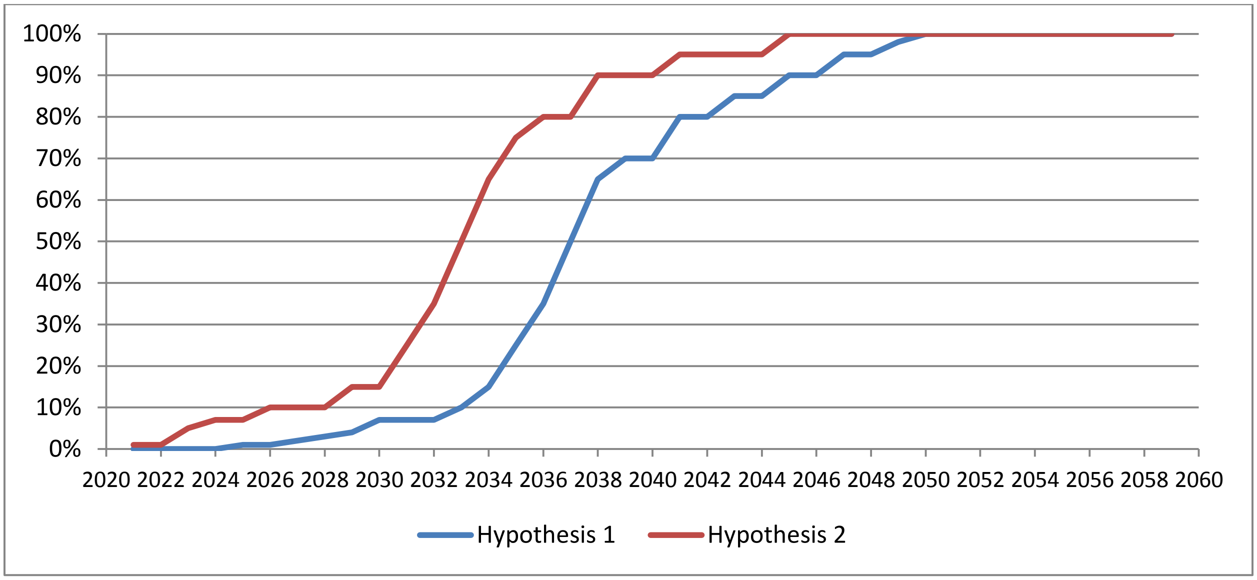


Figure V-7
Two Hypothetical Adoption Rate Scenarios for Full Automated Vehicles

Based on these adoption rates, the projected vehicle sales, and vehicle survivability rates, the agency was able to estimate the total percent of on-road light vehicle fleet that would be fully automated. Table xxx also shows these percentages. These percentages combined with the effectiveness of these technologies were used to derive the baseline adjustment factors. Multiplying these adjustment factors derive the new baseline that account for the effect of fully automated vehicles. Before 100 percent of on-road fleet becomes automated, a multi-vehicle crash can be one that involves (a) only fully automated vehicles, (b) both fully automated vehicles and non-fully automated vehicles, and (c) involves only non-fully automated vehicles. For the situation (b), we split the would-be at-fault drivers evenly between the fully automated

[103] Over $65,000 which was based on the criteria that was established by the 2016 Ward's Automotive Yearbook

vehicles and non-fully automated vehicles. Therefore, fully automated vehicles can only be effective against half of this type of crashes.

Let E represent the effectiveness of fully autonomous vehicles and P_i the portion of on-road fully autonomous vehicles at year i. Then, P_i*P_i is the estimated chance for a crash involving two fully autonomous vehicles for year i where $2*P_i*(1-P_i)$ is the estimated chance of a crash involving both fully automated vehicle and not fully automated vehicles for the same year. If B represents the baseline, then $B*VMT_i$ equals to the baseline for year i that accounts for the effect of VMT (VMT adjusted baseline). Deducting the benefits of the fully automated vehicles from the VMT adjusted baseline derives the new baseline that accounts for both effects of VMT and fully automated vehicles. This new baseline can be noted as:

$$\begin{aligned} \text{New Baseline} &= B*VMT_i - B*VMT_i*[P_i*P_i*E + P_i*(1-P_i)*E] \\ &= B*VMT_i*[1 - P_i*P_i*E + P_i*(1-P_i)*E]. \end{aligned}$$

Therefore, the adjustment factor for each year that takes into account both the impact of fully automated vehicles and the increase of VMT can be mathematically noted as:

$$A_i=VMT_i\ [1 - P_i*P_i*E-P_i*\left(1-P_i\right)*E] = \ VMT_i(1 - P_i*E)$$

Where, A_i = Adjustment factor for year i

VMT_i = Ratio of VMT in year i to the base VMT (i.e., 2021 MVT)

P_i = Percent of total fully autonomous vehicles in year i

E = The effectiveness of fully autonomous vehicles.

We do not have estimates for E. For the purpose of illustration and to simulate only the potential impact of fully autonomous vehicles over the horizon of this rulemaking, we hold VMT constant (i.e., VMT_i=1, no impact from projected VMT increase). Moreover, we give the technology the benefit of doubt and assume that fully autonomous vehicles would be mature as they roll out and can prevent 100 percent of driver errors, i.e., E=100 percent. This is likely to be a very generous assumption, but is intended to show the <u>maximum</u> potential impact of automated vehicles on the target population. Furthermore, without adjusting for the effect of VMT increase, the estimated adjustment factors cannot be treated as de facto discount factors that would be applicable to V2V.

In addition tohypothetical adoption rates, Table V-5 also presents the derived adjustment factors, and the percent of total on-road fully automated vehicles. Applying the adjustment factor for a specific year to the baseline derives the new baseline for that year. In interpreting these statistics, the first column serves both as MYs and calendar year with MYs for adoption rates and calendar for the remaining statistics.   As shown, if fully automated vehicles can prevent 100 percent of crashes related to driver error and if future baseline would not be affected by the increase of VMT, the fully automated vehicles would only slightly affect the V2V baseline for the first 10 years of V2V implementation under both hypothetical adoption scenarios. For Hypothesis 1, fully automated vehicles would reduce about 11 percent of the baseline target population by 2037 (i.e., adjusted by 89 percent), 50 percent by 2046, and 90 percent by 2059. In comparison, under Hypothesis 2, fully automated vehicles would reduce the baseline by 10 percent, 50 percent, and 90 percent in 2033, 2041, and 2053, respectively. The impact of fully automated vehicles on the estimated benefits of the proposed rule would follow the same patterns. Figure V-8 is the graphic presentation of the impact. The constant line at 100 percent represents the referenced constant baseline.

We need to reiterate that these are purely hypothetical adjustment levels and only for illustration purposes; these adjustment factors should not be taken as a prediction of the true effect of fully autonomous vehicles on the V2V baseline. These adjustment factors were derived based on assumptions for adoption rates and effectiveness, and ignore the impact of increasing VMT or assume that the effects of increasing VMT will be offset by other safety measures. Specifically, the assumption that full autonomous vehicles reduce 100 percent of crashes is likely to be unrealistically optimistic, as is the assumption that the risk of crashes would stay the same as today when the risk exposure, as measured by increased VMT, is projected to gradually increase over time. As a result, we believe these assumptions produce estimates of future baselines that are likely to overstate the impact of automated vehicles on the target population for the analysis supporting today's NPRM. We include this analysis to illustrate how to isolate the potential effect of future advanced technologies on our target population. .

Under these assumptions, the adjustment rates are small for the first 10 years and will not affect the estimated annual safety benefits of the proposed rule for those years. Therefore, the breakeven calendar year of the proposed rule will not be impacted. Similarly, the adjustment also will not affect the first MY vehicles that would become cost-beneficial (i.e., cost-effective and having positive net benefits). However, fully automated vehicles would reduce the lifetime cumulative benefit for later MY vehicles. In other words, the proposed rule would be cost-beneficial for a range of MYs vehicles and then become not cost-beneficial for later MYs vehicles. If we were also to take into account the projected increase in VMT, i.e., larger baseline light for benefit calculation, this would include more MYs vehicles that would be cost-beneficial and potentially push the non-cost-beneficial result after MY 2060. .

Table V-5
Adjustment Factors Taking Into Account the Impact of Fully Automated Vehicles
For two Hypothetical Adoption Scenarios

	Adoption Rate		Percent of On-Road Fully Automated Vehicles		Adjustment factor	
Year*	Hypothesis 1	Hypothesis 2	Hypothesis 1	Hypothesis 2	Hypothesis 1	Hypothesis 2
2021	0%	1%	0%	0%	100%	100%
2022	0%	1%	0%	0%	100%	100%
2023	0%	5%	0%	0%	100%	100%
2024	0%	7%	0%	1%	100%	99%
2025	1%	7%	0%	1%	100%	99%
2026	1%	10%	0%	2%	100%	98%
2027	2%	10%	0%	3%	100%	97%
2028	3%	10%	0%	3%	100%	97%
2029	4%	15%	1%	4%	99%	96%
2030	7%	15%	1%	5%	99%	95%
2031	7%	25%	2%	7%	98%	93%
2032	7%	35%	2%	9%	98%	91%
2033	10%	50%	3%	12%	97%	88%
2034	15%	65%	4%	16%	96%	84%
2035	25%	75%	5%	20%	95%	80%
2036	35%	80%	7%	25%	93%	75%
2037	50%	80%	11%	30%	89%	70%

2038	65%	90%	15%	35%	85%	65%
2039	70%	90%	19%	40%	81%	60%
2040	70%	90%	23%	45%	77%	55%
2041	80%	95%	28%	50%	72%	50%
2042	80%	95%	33%	55%	67%	45%
2043	85%	95%	37%	59%	63%	41%
2044	85%	95%	42%	63%	58%	37%
2045	90%	100%	46%	67%	54%	33%
2046	90%	100%	51%	71%	49%	29%
2047	95%	100%	55%	75%	45%	25%
2048	95%	100%	60%	78%	40%	22%
2049	98%	100%	64%	81%	36%	19%
2050	100%	100%	68%	83%	32%	17%
2051	100%	100%	72%	86%	28%	14%
2052	100%	100%	75%	88%	25%	12%
2053	100%	100%	78%	90%	22%	10%
2054	100%	100%	75%	91%	19%	9%
2055	100%	100%	71%	92%	16%	8%
2056	100%	100%	67%	94%	14%	6%
2057	100%	100%	63%	95%	12%	5%
2058	100%	100%	59%	95%	11%	5%
2059	100%	100%	54%	96%	9%	4%

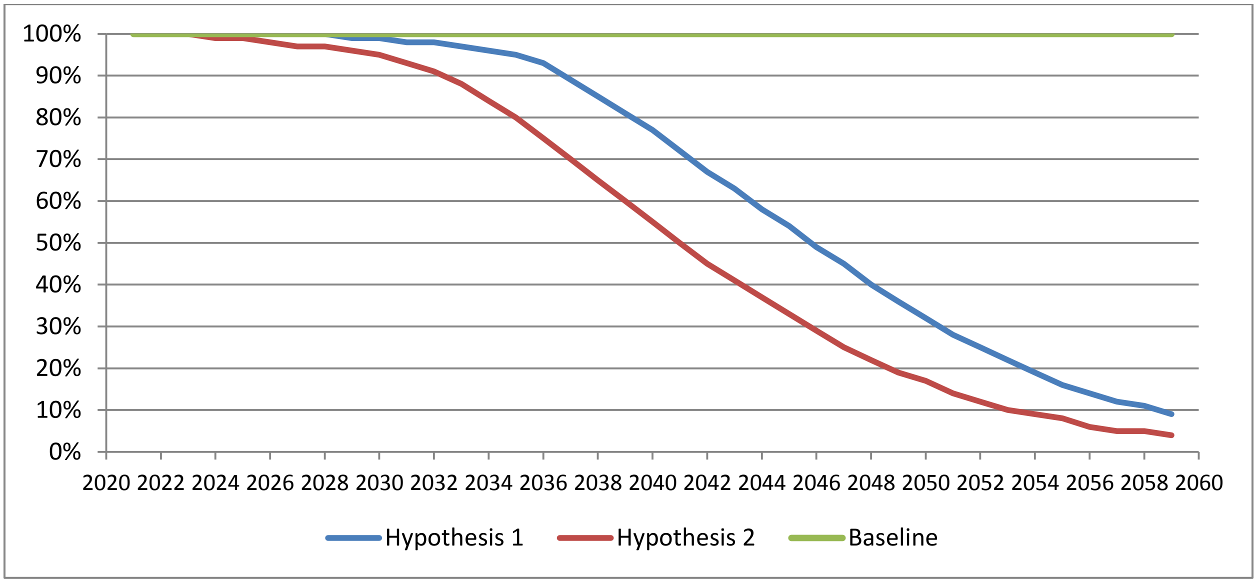


Figure V-8
Proportion of Baseline after Accounting for Fully Autonomous Vehicles

NHTSA seeks comment on the baseline issue, and specifically seeks information on the effectiveness, cost, and development pace of technologies, including both highly automated vehicles and lower-level technologies, which might mitigate the intersection turning crashes that constitute the target population measured in this analysis.

B. DSRC Radio and App Adoption Rates

As shown in the generic benefit formula above, the communication rate (C_i) represents the probability of a crash where the involved vehicles were DSRC-equipped light vehicles and the app designing to that crash was activated. So, C_i depends on the number of vehicles that have DSRC radios and apps and these numbers depend on the technology adoption rates. Therefore, the DSRC radio and apps adoption rates are discussed first.

For DSRC, the proposed rule would require that all applicable vehicles are equipped with a DSRC radios. The DSRC radio adoption schedule follows the proposed three year phase-in schedule: 50 percent of the first MY vehicles, 75 percent of the second MY vehicles, and 100 percent of the third MY vehicles.

However, for safety apps, since the agency is not proposing to mandate any at this time, for this analysis, they are projected to be introduced based on a market-driven adoption rate estimated by the agency. The agency believes that requiring the DSRC radios will spur the market for V2V-based apps due to small estimated incremental costs over the DSRC radios. To get a better sense of the potential adoption of apps, the agency contracted the Intelligent Transportation Society of America (ITS America, or ITS) to conduct a study to understand the utilization of DSRC among stakeholders and to determine the potential app deployment and product development.[104] As part of the effort, ITS identified an array of V2V and vehicle-to-infrastructure (V2I) apps and interviewed 42 stakeholders specifically about these apps' development and deployment. The

[104] Impact of Light Vehicle Rule on Consumer/Aftermarket Adoption- Dedicated Short Range Communications Market Study, Intelligent Transportation Society of America, TBD

stakeholders included chipset manufacturers, mobile device manufacturers, infrastructure industrial equipment makers, vehicle original equipment manufacturers (OEMs), and academia. Based on the interview results, ITS America concluded that about 91 apps (including both V2V and V2I) would likely to be deployed within 5 years of a DSRC mandate. IMA and LTA were rated among the highest priority apps among all the interviewees.

The ITS study confirmed many aspects of the agency's proposed requirements and assumptions regarding potential V2V deployment including the proposed implementation timing. However, the study was not able to predict clearly a safety application adoption trend after an initial deployment. To fill this gap and establish a potential trend, the agency examined the adoption patterns of the three crash avoiding warning systems reported as part of regular data submissions associated with the agency's New Car Assessment Program (NCAP). The crash avoiding warning systems are blind spot detection (BSD), forward collision warning (FCW), and Lane Departure Warning (LDW). We note that only FCW and LDW are currently reported on NHTSA's Safer Car technologies as being "Recommended Technologies," while BSD is reported to NHTSA for research purposes but not, at this time, presented to the public. Table V-6 lists the adoption rates for these systems that were offered as standard equipment and the combined adoption rates for the technologies offered as standard or optional.

Table V-6
Reported Adoption Rates in NCAP

Year	BSD*		FCW		LDW	
	Standard	Combined*	Standard	Combined**	Standard	Combined**
2011	0.3	11.9	0.0	11.4	0.0	2.5
2012	1.0	30.0	0.0	11.4	0.0	5.9
2013	1.3	30.4	0.8	21.0	0.0	17.4
2014	0.1	27.0	2.6	22.1	0.2	15.8
2015	0.6	45.7	5.6	57.3	2.5	52.7

*obtained through NCAP, not required to be reported
**standard equipment and optional equipment combined.

As shown, the rate of the standard equipment is relatively low, although it increases gradually. In contrast, the rate for the optional equipment (based on the combined rates) was much higher and the pace of the offering increased faster. These warning technologies are projected to reach the full combined deployment before 2021 based on a curve linear regression model. For each of these three technologies, the combined rate is the dependent variable in the regression model. The years after the system was first introduced and its square term are the independent variables. These regression models can be mathematically noted as:

$$Rc = a_0 + Y*a_1 + Y^2*a_2$$

Where, Rc = combined adoption rate

Y = year after the technology is first introduced (=1 if it is the first year)

a_0, a_1 and a_2 are parameters.

The following shows the a_0, a_1, a_2, and the adjusted R^2 (i.e., Adj R^2) for BSD, FCW, and LDW as well as the year that the combined adoption rates are projected to reach 100 percent:

BSD	FCW	LDW
a_0 = -0.00518 a_1 = -0.10042 a_2 = 0.00351 Adj R^2 = 0.7855 Year = 2020	a_0 = 0.07232 a_1 = -0.07483 a_2 = 0.01019 Adj R^2 = 0.7605 Year = 2018	a_0 = 0.09458 a_1 = -0.10042 a_2 = 0.01076 Adj R^2 = 0.7546 Year = 2018

The agency believes that the combined adoption rates of standard equipment and optional equipment would most likely represent the maturity of the technologies and the willingness of the industry to deploy these technologies. That is, if industry is willing to include these technologies as an option on a significant number of models, it is reasonable to assume that these technologies are at a relatively mature stage that is not cost-prohibitive for many consumers. This is a particularly salient point for V2V-enabled technologies, including IMA and LTA because, based on our cost estimates, we believe the apps will be most likely adopted faster after all applicable vehicles are required to have a DSRC radio. The cost of an app (either IMA or LTA) is estimated to be $1.00 above the cost of the radio, which is less than 1 percent of the cost of a DSRC radio (please see the cost chapter).[105] Given that the cost of an app is significantly lower than the $300 unit cost estimated for each of vehicle-resident FCW and LDW, we believe that manufacturers are likely to implement these V2V apps (IMA and LTA) more aggressively than that of the combined rates of FCW and LDW. Finally, we believe that IMA and LTA will

[105] The estimated cost for 1 DSRC radio and 2 radios is $247 and $349, respectively

be quickly deployed by manufacturers soon after a DSRC mandate since several manufacturers already have the prototype systems or/and the research and deployment plans on these two apps.

Thus, the agency assumes that IMA and LTA will be adopted as standard equipment on a schedule similar to the "combined" schedules for the FCW and LDW displayed in the NCAP data above. Based on the ITS study, NCAP data, the announcement on V2V implementation from vehicle industry, and the cost consideration, the agency established the app adoption trend as 0% for the first MY vehicles that have DSRC radios, 5%, 10%, 25%, 40%, 65%, 90%, and 100% for each following MY vehicles, respectively. The agency believes that this adoption rate is reasonable. We note that the pattern is similar to those shown as the combined rates in the NCAP data; they start low and stay low for two initial years and after the initial years the pace increases until they reach their full adoption. Under this adoption scenario, IMA and LTA would not be deployed in the first year. In the second year, with the required 75 percent DSRC installation rate and the 5 percent app adoption among the DSRC-equipped vehicles, 5 percent of the total new vehicles (= 0.05 * 0.75) are expected to have the two apps. In the third year, 10 percent of the new vehicles (= 0.1 * 1.00) would have the apps, and so on so forth.

The benefits (and costs) of the proposed rule were estimated based on this specific technology adoption scenario, as shown in Table V-7. Figure V-9 is the graphic presentation of the DSRC and app adoption rates.

Table V-7
V2V Technology Adoption Scenario for Cost and Benefit Estimates

Year (MY)	1 (2021)	2 (2022)	3 (2023)	4 (2024)	5 (2025)	6 (2026)	7 (2027)	8 (2028)
DSRC	50%	75%	100%	100%	100%	100%	100%	100%
Apps*	0%	5%	10%	25%	40%	65%	90%	100%
Apps Actual**	0%	4%	10%	25%	40%	65%	90%	100%

*IMA and LTA of DSRC-equipped new vehicles
**of all new vehicles

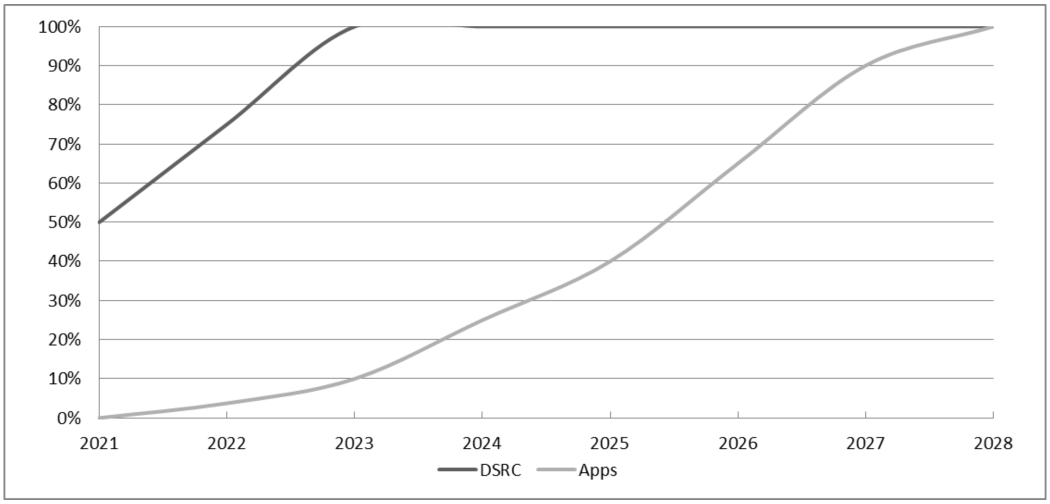


Figure V-9
DSRC and App Adoption Rates

Table V-8 presents the projected annual vehicles sales, the number of new vehicles that would be equipped with DSRC radios and apps for MY 2021 to MY 2060 under the above technology adoption scenario. In 2021, we project that a total of 16.19 million vehicles would be sold in the U.S. Of these, 8.10 million would be equipped with DSRC radios but none would have the apps. In 2023, all projected 16.44 million vehicles would have DSRC radios and 0.61 million of these vehicles would have the apps. Under the app adoption rate, the apps would not reach the full deployment until 2028. Until then, therefore, the number of vehicles with the apps will be smaller than the total sales.

The projected annual vehicle sales were derived based on a linear regression model that was developed for the ANPRM. The regression was based on the vehicle sales from 1994 to 2011, which were available at the time of the ANPRM.[106] However, based on the most currently available data, the regression seems to overestimate the PC sales and underestimate the LTV sales for MY 2012 and 2013. Therefore, in the PRIA, we further adjusted the initially projected sales by the ratio of 2013 sales[107] to the sales projected in the ANPRM. Based on the ratio, we adjusted the projected PC and LTV sales by 0.89 and 1.02, respectively. As a result, the

[106] Ward's Automotive Yearbook

[107] Based on the Ward's Automotive Yearbook 2014

projected PC sales for MY 2014 and newer vehicles used in the PRIA were 11 percent lower than those in the ANPRM. Similarly, the projected LTV sales were 2 percent higher.

Table V-8
Projected Annual Vehicle Sales and New Vehicles Would Have the V2V Technology
(in millions)

Year	Model Year	Projected Sales			New Vehicles With DSRC			New Vehicles With Apps		
		PCs	LTVs	Total	PCs	LTVs	Total	PCs	LTVs	Total
1	2021	8.25	7.94	16.19	4.13	3.97	8.10	0.00	0.00	0.00
2	2022	8.33	8.01	16.34	6.25	6.01	12.26	0.31	0.30	0.61
3	2023	8.38	8.06	16.44	8.38	8.06	16.44	0.84	0.81	1.64
4	2024	8.43	8.10	16.53	8.43	8.10	16.53	2.11	2.03	4.13
5	2025	8.50	8.17	16.67	8.50	8.17	16.67	3.40	3.27	6.67
6	2026	8.54	8.21	16.75	8.54	8.21	16.75	5.55	5.34	10.89
7	2027	8.61	8.27	16.88	8.61	8.27	16.88	7.75	7.44	15.19
8	2028	8.69	8.34	17.03	8.69	8.34	17.03	8.69	8.34	17.03
9	2029	8.74	8.39	17.13	8.74	8.39	17.13	8.74	8.39	17.13
10	2030	8.82	8.48	17.30	8.82	8.48	17.30	8.82	8.48	17.30
11	2031	8.89	8.55	17.44	8.89	8.55	17.44	8.89	8.55	17.44
12	2032	8.95	8.61	17.56	8.95	8.61	17.56	8.95	8.61	17.56
13	2033	9.01	8.66	17.67	9.01	8.66	17.67	9.01	8.66	17.67
14	2034	9.10	8.74	17.84	9.10	8.74	17.84	9.10	8.74	17.84
15	2035	9.18	8.82	18.00	9.18	8.82	18.00	9.18	8.82	18.00
16	2036	9.26	8.90	18.16	9.26	8.90	18.16	9.26	8.90	18.16
17	2037	9.35	8.99	18.34	9.35	8.99	18.34	9.35	8.99	18.34
18	2038	9.43	9.06	18.49	9.43	9.06	18.49	9.43	9.06	18.49
19	2039	9.51	9.15	18.66	9.51	9.15	18.66	9.51	9.15	18.66
20	2040	9.62	9.25	18.87	9.62	9.25	18.87	9.62	9.25	18.87
21	2041	9.76	9.38	19.14	9.76	9.38	19.14	9.76	9.38	19.14
22	2042	9.18	9.38	18.56	9.18	9.38	18.56	9.18	9.38	18.56
23	2043	9.23	9.43	18.66	9.23	9.43	18.66	9.23	9.43	18.66
24	2044	9.27	9.49	18.76	9.27	9.49	18.76	9.27	9.49	18.76
25	2045	9.32	9.55	18.87	9.32	9.55	18.87	9.32	9.55	18.87
26	2046	9.37	9.60	18.97	9.37	9.60	18.97	9.37	9.60	18.97
27	2047	9.42	9.66	19.08	9.42	9.66	19.08	9.42	9.66	19.08
28	2048	9.46	9.72	19.18	9.46	9.72	19.18	9.46	9.72	19.18
29	2049	9.51	9.77	19.28	9.51	9.77	19.28	9.51	9.77	19.28
30	2050	9.56	9.83	19.39	9.56	9.83	19.39	9.56	9.83	19.39
31	2051	9.56	9.83	19.39	9.56	9.83	19.39	9.56	9.83	19.39
32	2052	9.56	9.83	19.39	9.56	9.83	19.39	9.56	9.83	19.39
33	2053	9.56	9.83	19.39	9.56	9.83	19.39	9.56	9.83	19.39
34	2054	9.56	9.83	19.39	9.56	9.83	19.39	9.56	9.83	19.39
35	2055	9.56	9.83	19.39	9.56	9.83	19.39	9.56	9.83	19.39
36	2056	9.56	9.83	19.39	9.56	9.83	19.39	9.56	9.83	19.39
37	2057	9.56	9.83	19.39	9.56	9.83	19.39	9.56	9.83	19.39
38	2058	9.56	9.83	19.39	9.56	9.83	19.39	9.56	9.83	19.39
39	2059	9.56	9.83	19.39	9.56	9.83	19.39	9.56	9.83	19.39
40	2060	9.56	9.83	19.39	9.56	9.83	19.39	9.56	9.83	19.39

Table V-9 shows the same information as those in Table V-8 but for the total on road fleet of light vehicles. Table V-10 presents the corresponding percentage that have DSRC radios and that have apps. The projected annual on-road fleet is derived from the historical vehicle sales, projected vehicles sales shown in the above table, and the vehicle survival rates that were established by the agency. The agency estimated that a total of 8.1 million light vehicles will be equipped with the DSRC radios in 2021 and none of these vehicles would be expected to have the IMA and LTA. In 2022, a total of 20.21 million light vehicles will have the DSRC radios and 0.6 million of these vehicles will have the two apps. In 2057, all on-road light vehicles will have the V2V communication capability and 99.4 percent will have the apps. These projected on-road fleets were used to calculate the probability of a crash to occur when the involved vehicles are communicating with each other and would activate the apps in crashes (i.e., communication rate). Note that Appendix A presents the background information and discusses the vehicle sale projection process.

Table V-9
Projected On-Road Light Vehicles and Vehicles That Would Have the V2V Technology
(Millions)

Year	Calendar Year	Projected On-Road Fleet			On-Road fleet With DSRC			On-Road Fleet With Apps		
		PCs	LTVs	Total	PCs	LTVs	Total	PCs	LTVs	Total
1	2021	117.51	124.52	242.03	4.13	3.97	8.10	0.00	0.00	0.00
2	2022	118.33	125.15	243.48	10.32	9.89	20.21	0.31	0.30	0.61
3	2023	119.26	125.79	245.05	18.58	17.76	36.34	1.15	1.10	2.25
4	2024	120.27	126.45	246.72	26.78	25.51	52.28	3.24	3.10	6.34
5	2025	121.40	127.15	248.55	34.92	33.21	68.13	6.60	6.31	12.91
6	2026	122.60	127.87	250.47	42.97	40.82	83.79	12.07	11.52	23.59
7	2027	123.87	128.65	252.52	50.94	48.35	99.29	19.66	18.74	38.40
8	2028	125.17	129.49	254.66	58.84	55.77	114.61	28.09	26.73	54.82
9	2029	126.43	130.34	256.77	66.60	63.03	129.64	36.44	34.62	71.06
10	2030	127.66	131.21	258.87	74.24	70.09	144.33	44.74	42.45	87.19
11	2031	128.84	132.07	260.91	81.66	76.85	158.51	52.94	50.19	103.14
12	2032	129.96	132.90	262.86	88.80	83.25	172.05	61.04	57.80	118.84
13	2033	131.04	133.69	264.73	95.61	89.28	184.89	68.99	65.21	134.20
14	2034	132.10	134.47	266.57	102.08	94.94	197.02	76.79	72.40	149.19
15	2035	133.16	135.24	268.40	108.15	100.25	208.39	84.39	79.32	163.71
16	2036	134.21	136.06	270.27	113.79	105.20	218.98	91.72	85.91	177.62
17	2037	135.29	136.92	272.21	118.93	109.84	228.78	98.73	92.15	190.88
18	2038	136.40	137.81	274.21	123.53	114.16	237.70	105.38	98.01	203.39
19	2039	137.55	138.76	276.31	127.56	118.18	245.73	111.61	103.52	215.13
20	2040	138.73	139.77	278.50	131.06	121.90	252.96	117.40	108.69	226.09
21	2041	139.98	140.88	280.86	134.12	125.37	259.49	122.75	113.57	236.32
22	2042	140.55	141.97	282.52	136.11	128.46	264.57	126.90	118.03	244.93
23	2043	141.11	143.08	284.19	137.75	131.29	269.04	130.47	122.14	252.61
24	2044	141.65	144.21	285.86	139.12	133.89	273.00	133.46	125.91	259.37
25	2045	142.17	145.38	287.55	140.28	136.32	276.60	135.93	129.36	265.29
26	2046	142.69	146.56	289.25	141.31	138.61	279.92	137.97	132.49	270.46
27	2047	143.20	147.69	290.89	142.23	140.81	283.04	139.64	135.36	274.99
28	2048	143.70	148.78	292.48	143.05	142.93	285.97	141.02	137.99	279.01
29	2049	144.18	149.84	294.02	143.80	144.93	288.73	142.19	140.44	282.62
30	2050	144.66	150.88	295.54	144.50	146.84	291.34	143.20	142.74	285.94
31	2051	145.08	151.85	296.93	145.03	148.61	293.64	144.05	144.86	288.90
32	2052	145.45	152.75	298.20	145.45	150.24	295.69	144.76	146.82	291.58
33	2053	145.78	153.59	299.37	145.78	151.73	297.51	145.35	148.64	294.00
34	2054	146.07	154.38	300.45	146.07	153.08	299.15	145.84	150.31	296.15
35	2055	146.32	155.12	301.44	146.32	154.27	300.60	146.23	151.84	298.07
36	2056	146.54	155.79	302.33	146.54	155.32	301.86	146.52	153.23	299.75
37	2057	146.73	156.41	303.14	146.73	156.22	302.96	146.73	154.48	301.21
38	2058	146.91	156.97	303.88	146.91	156.91	303.82	146.91	155.59	302.50
39	2059	147.07	157.48	304.55	147.07	157.48	304.54	147.07	156.56	303.63
40	2060	147.22	157.93	305.15	147.22	157.93	305.15	147.22	157.38	304.60

Table V-10
Projected Percentage of On-Road Light Vehicles and Vehicles That Would Have the V2V Technology

Year	Calendar Year	With DSRC Radios	With Apps
1	2021	3.3%	0.0%
2	2022	8.3%	0.3%
3	2023	14.8%	0.9%
4	2024	21.2%	2.6%
5	2025	27.4%	5.2%
6	2026	33.5%	9.4%
7	2027	39.3%	15.2%
8	2028	45.0%	21.5%
9	2029	50.5%	27.7%
10	2030	55.8%	33.7%
11	2031	60.8%	39.5%
12	2032	65.5%	45.2%
13	2033	69.8%	50.7%
14	2034	73.9%	56.0%
15	2035	77.6%	61.0%
16	2036	81.0%	65.7%
17	2037	84.0%	70.1%
18	2038	86.7%	74.2%
19	2039	88.9%	77.9%
20	2040	90.8%	81.2%
21	2041	92.4%	84.1%
22	2042	93.6%	86.7%
23	2043	94.7%	88.9%
24	2044	95.5%	90.7%
25	2045	96.2%	92.3%
26	2046	96.8%	93.5%
27	2047	97.3%	94.5%
28	2048	97.8%	95.4%
29	2049	98.2%	96.1%
30	2050	98.6%	96.8%
31	2051	98.9%	97.3%
32	2052	99.2%	97.8%
33	2053	99.4%	98.2%
34	2054	99.6%	98.6%
35	2055	99.7%	98.9%
36	2056	99.8%	99.1%
37	2057	99.9%	99.4%
38	2058	100.0%	99.5%
39	2059	100.0%	99.7%
40	2060	100.0%	99.8%

C. Effectiveness (E) of IMA and LTA

As described in Chapter IV, the effectiveness of IMA and LTA was derived using the SIM tool. SIM tool is a computer-based simulator that uses the Monte Carlo technique to estimate the crash rates for vehicles with and without the V2V technology. We derived the effectiveness by comparing these crashes rates. (See Chapter IV for the discussion on the process.) Table V-11 shows the effectiveness of IMA and LTA.

Table V-11
App Effectiveness of IMA and LTA

Apps	Low	High
IMA	43%	56%
LTA	37%	63%

D. Communication Rate (C_i)

The communication rate (C_i) represents the probability of vehicles involved in a crash having the capability to talk to each other and activate safety apps. Therefore, C_i is a function of the number of on-road light vehicles, the number of these vehicles with DSRC radios, and the number of these vehicles with the apps. The on-road fleet statistics shown in Table V-8 were used to calculate the C_i. Since the establishment of on-road fleet requires vehicle survival rate (or scrappage rates) and PCs and LTVs have different rates, C_i was developed separately for PCs and LTVs. For a given app-equipped vehicle of a particular type (i.e., PCs or LTVs), there are four possible communication scenarios with the other vehicle involved in the crash: (1) the other vehicle is also of the same type (for example PC communicating with PC) and has a DSRC radio and the apps, (2) the other vehicle is also of the same type and has a DSRC radio but no apps, (3) the other vehicle is not the same type (for example PC communicating with LTV) and has a DSRC radio with the apps, or (4) the other vehicle is not the same vehicle type and has a DSRC radio but no apps. Therefore, C_i is the sum of these four probabilities. For the second to the third scenarios, each scenario has two possible permutations since either vehicle can be the app-equipped vehicle. For the first scenario, there is only one permutation since both are the same type of vehicles and both have the apps. Furthermore, the third scenario (3) involves two different types of vehicles and both have the apps. To keep from duplicating the benefit estimate, this communication probability is shared between both vehicles, i.e., each vehicle type takes one condition. With this process, the communication rates for PCs and LTVs are mutually exclusive and additive. When the rates are combined, it represents the overall communication rate for all light vehicles.

For example, for simplicity let PC and LTV represents the PC and LTV that had DSRC, the communication scenarios for a crash for a PC are:

(1) V1: PC with apps to V2: PC with apps (no mutational condition since both had apps)
(2) V1: PC with apps to V2: PC, no apps <u>or</u> V1: PC no apps to V2: PC with apps
(3) V1: PC with apps to V2: LTV with apps <u>or</u> V1: LTV with apps to V2: PC with apps
(4) V1: PC with apps" to "LTV no apps <u>or</u> V1: LTA no apps to V2: PC with apps

For scenarios (1), (2), and (4), benefits all credited to the PC since PC is the one had apps. However, for (3), the benefit was shared between PC and LTV. Each vehicle takes half the scenario, i.e., one permutation.

Therefore, C_i for IMA can be represented by the following formula since either vehicle in an IMA crash can activate IMA and potentially prevent the crash:

$$C_i = \frac{P_i^A}{O_i} * \frac{P_i^A}{O_i} + 2 * \frac{P_i^A}{O_i} * \frac{P_i^N}{O_i} + \frac{P_i^A}{O_i} * \frac{L_i^A}{O_i} + 2 * \frac{P_i^A}{O_i} * \frac{L_i^N}{O_i} ------ (1)$$

Where,

C_i=communication rate at year i

P_i^A=cars with apps

P_i^N=cars with DSRC radios, but no apps

L_i^A=light trucks vans with apps

L_i^N=light trucks and vans with DSRC radios, but without apps

O_i=total on-road light vehicles

The coefficient 2 represents the two possible combinations.

In contrast, for LTA, a crash can potentially be prevented only if the left-turning vehicle has the app. Therefore, there is only one permutation for the above communication scenarios (2) and (4) that can prevent the crash. The C_i for LTA is expressed as following:

$$C_i = \frac{P_i^A}{O_i} * \frac{P_i^A}{O_i} + \frac{P_i^A}{O_i} * \frac{P_i^N}{O_i} + \frac{P_i^A}{O_i} * \frac{L_i^A}{O_i} + \frac{P_i^A}{O_i} * \frac{L_i^N}{O_i} ---------(--------- (2)$$

Note that vehicles that can communicate with other vehicles that have apps should be treated as selection without replacement. In other words, the probability of selecting the second involved vehicle from the remaining vehicles would be the total minus one. For example, the first term of the formula (1) should be $\frac{P_i^A}{O_i} * \frac{P_i^A - 1}{O_i - 1}$. However, since P_i^A, P_i^N, L_i^A, L_i^N, and O_i are large, their values are almost identical when they are reduced by one. Thus, for simplicity, the formula for selection with replacement (i.e., no minus one format) is used for calculating the communication rate C_i. Also note that communication rates for crashes involved three-vehicle crashes were treated as two-vehicle crashes since our crash database shows that these crashes started with the collision of only two vehicles not of three vehicles at the same time. In addition, the difference in C_i among geographic areas and driving patterns by different age of vehicles were not examined in the analysis since these factors are not expected to impact the overall communication rate at the national level.

Based on the above formulas, to derive the communication rates, we need the number of vehicles that would have DSRC radios ($P_i^A + P_i^N$ and $L_i^A + L_i^N$), the total number of vehicles that would have the apps (P_i^A and L_i^A), and the total number of vehicles in the on-road light vehicle fleet (O_i).

Table V-12 shows the communication rates from 2021 to 2060 by vehicle type (i.e., PCs, LTVs, and PCs and LTVs combined) separately for IMA and LTA. As expected, the communication rates would be relatively small in the first few years and accelerate faster when time progresses.

The overall communication with vehicles that had the apps would be rare in the first three years as measured by those rates for IMA. The rate would reach over 50 percent (51.41%) in 2034, the 14th year of the implementation of the proposed rule. In 2039, 5 years later, the rate would reach 75 percent. In 2044, the communication rate would reach over 90 percent.

For LTA, the communication rates would be smaller than the general communication rates. In 2022, for example, the contributable rate for LTA with vehicles equipped with the apps is about 0.02 percent, 50 percent of the overall communication rate. However, the ratio would increase over time and narrow the difference between these two rates. In 2034, the rate for LTA would be 41.36 percent, 80.5 percent of the overall communicating rate.

Table V-12
Light Vehicle Fleet Communication Rates

Year	Calendar Year	IMA			LTA		
		PCs	LTVs	Combined	PCs	LTVs	Combined
1	2021	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
2	2022	0.02%	0.02%	0.04%	0.01%	0.01%	0.02%
3	2023	0.13%	0.13%	0.26%	0.07%	0.07%	0.14%
4	2024	0.52%	0.50%	1.02%	0.28%	0.27%	0.55%
5	2025	1.32%	1.26%	2.58%	0.73%	0.70%	1.43%
6	2026	2.77%	2.64%	5.41%	1.61%	1.54%	3.15%
7	2027	4.94%	4.71%	9.65%	3.06%	2.92%	5.98%
8	2028	7.55%	7.19%	14.74%	4.96%	4.72%	9.68%
9	2029	10.40%	9.88%	20.28%	7.17%	6.81%	13.98%
10	2030	13.45%	12.76%	26.21%	9.63%	9.14%	18.77%
11	2031	16.63%	15.77%	32.40%	12.33%	11.69%	24.02%
12	2032	19.90%	18.84%	38.74%	15.20%	14.39%	29.59%
13	2033	23.19%	21.92%	45.11%	18.20%	17.20%	35.40%
14	2034	26.46%	24.95%	51.41%	21.29%	20.07%	41.36%
15	2035	29.65%	27.87%	57.52%	24.41%	22.95%	47.36%
16	2036	32.69%	30.62%	63.31%	27.50%	25.75%	53.25%
17	2037	35.53%	33.16%	68.69%	30.48%	28.45%	58.93%
18	2038	38.12%	35.46%	73.58%	33.31%	30.98%	64.29%
19	2039	40.40%	37.47%	77.87%	35.92%	33.32%	69.24%
20	2040	42.36%	39.21%	81.57%	38.29%	35.45%	73.74%
21	2041	43.99%	40.69%	84.68%	40.38%	37.36%	77.74%
22	2042	45.18%	42.03%	87.21%	42.06%	39.12%	81.18%
23	2043	46.11%	43.17%	89.28%	43.46%	40.69%	84.15%
24	2044	46.81%	44.17%	90.98%	44.59%	42.07%	86.66%
25	2045	47.33%	45.04%	92.37%	45.47%	43.27%	88.74%
26	2046	47.72%	45.83%	93.55%	46.16%	44.33%	90.49%
27	2047	48.04%	46.56%	94.60%	46.71%	45.28%	91.99%
28	2048	48.29%	47.25%	95.54%	47.14%	46.13%	93.27%
29	2049	48.49%	47.90%	96.39%	47.49%	46.91%	94.40%
30	2050	48.65%	48.50%	97.15%	47.77%	47.61%	95.38%
31	2051	48.75%	49.02%	97.77%	47.97%	48.24%	96.21%
32	2052	48.81%	49.50%	98.31%	48.14%	48.82%	96.96%
33	2053	48.82%	49.93%	98.75%	48.25%	49.34%	97.59%
34	2054	48.81%	50.31%	99.12%	48.33%	49.81%	98.14%
35	2055	48.78%	50.65%	99.43%	48.37%	50.23%	98.60%
36	2056	48.73%	50.96%	99.69%	48.39%	50.60%	98.99%
37	2057	48.65%	51.22%	99.87%	48.37%	50.93%	99.30%
38	2058	48.54%	51.41%	99.95%	48.33%	51.19%	99.52%
39	2059	48.43%	51.56%	99.99%	48.29%	51.41%	99.70%
40	2060	48.33%	51.67%	100.00%	48.25%	51.57%	99.82%

Figure V-10 is the graphic presentation of the communication rates for all light vehicles. The upper curve represents the communication rate for IMA and the lower curve represents the rate for LTA. The IMA and LTA communication rates for different types of vehicles would follow the same patterns of these two curves.

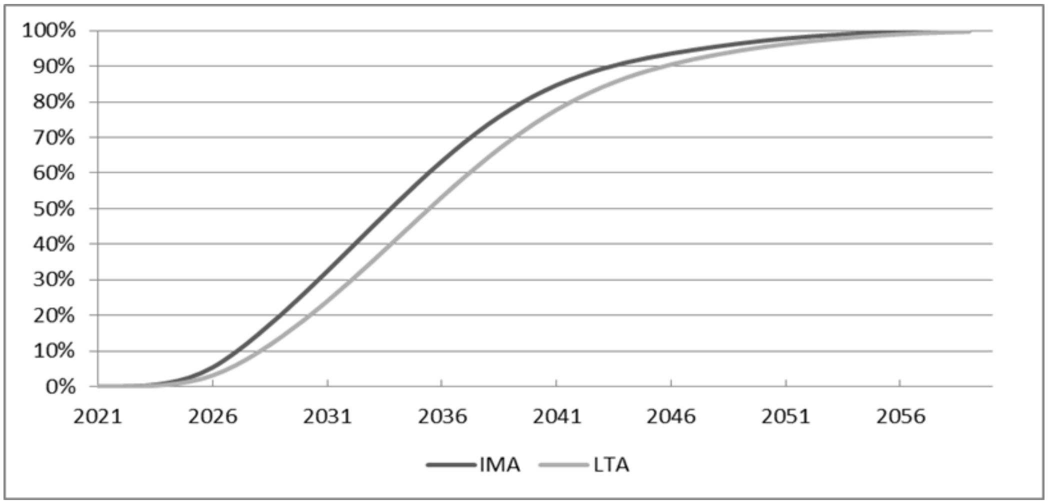


Figure V-10
Communication Rates for Light Vehicles with IMA and LTA

E. Annual Benefits

This section derives the annual benefits based on the target population, effectiveness, and communication rates that were established in the previous sections. As described earlier, the annual benefits represent the collective savings accrued by all applicable MY vehicles for a specific calendar year. Table V-13 shows the undiscounted annual maximum benefits when all light vehicles were equipped with DSRC and the apps. As shown, IMA and LTA combined are estimated to prevent 439,322 to 615,359 crashes, save 987 to 1,366 lives, reduce 305,131 to 417,613 MAIS 1-5 injuries, and eliminate 536,869 to 746,357 property-damage-only vehicles (PDOVs). The range of benefits reflects the range of effectiveness of the IMA and LTA. The annual maximum benefits can be achieved around 43 years after the implementation of the proposed rule when all light vehicles have DSRC radios and apps. For IMA, the benefits include crash avoidance and crashworthiness benefits (very small). For LTA, the benefits are from crash avoidance.

Separately, IMA would prevent a maximum of 331,421 to 431,619 crashes, save 784 to 1,021 lives, reduce 224,592 to 280,479 MAIS 1-5 injuries, and eliminate 419,033 to 545,718 PDOVs annually. Whereas, LTA would prevent 107,911 to 183,740 crashes, save 203 to 345 lives, reduce 80,539 to 137,134 MAIS 1-5 injuries, and eliminate 117,836 to 200,639 PDOVs.

Table V-13
Undiscounted Annual Maximum Benefits*

	IMA		LTA		Combined	
	Low	High	Low	High	Low	High
Crashes	331,421	431,619	107,911	183,740	439,332	615,359
Fatalities	784	1,021	203	345	987	1,366
MAIS1-5 Injuries	224,592	280,479	80,539	137,134	305,131	417,613
PDOV**	419,033	545,718	117,836	200,639	536,869	746,357

*when all vehicles had DSRC radios and apps
**Property Damage Only Vehicles

Table V-14 presents the undiscounted annual benefits from 2021 to 2060. It shows that the expected benefits after 40 years are very close the maximum benefits. Therefore, these benefits are not presented in the table. As shown, the annual benefits of the proposed rule are negligible for the first year. However, after the first year, the benefits would progressively increase. In 2030, the proposed rule would prevent 107,120 to 147,615 crashes. By preventing theses crashes, the proposed rule would save 244 to 332 lives and reduce 73,983 to 99,254 MAIS 1-5 injuries. In addition, the proposed rule would eliminate 131,946 to 180,639 PDOVs in 2030. In 2060, the 40th year of the implementation of the proposed rule, the annual benefits would be very close to the maximum level as shown in Table V-13.

Table V-14
Annual Benefits of the Proposed Rule
(Undiscounted)

	Calendar	Crash Prevented		Fatalities Eliminated		MAIS 1-5 Injuries		PDOVs	
Year	Year	Low	High	Low	High	Low	High	Low	High
1	2021	0	0	0	0	0	0	0	0
2	2022	154	209	0	0	106	140	191	258
3	2023	1,013	1,379	2	3	697	921	1,254	1,700
4	2024	3,974	5,413	9	12	2,734	3,615	4,922	6,670
5	2025	10,094	13,763	23	31	6,946	9,197	12,496	16,949
6	2026	21,329	29,138	49	66	14,687	19,494	26,382	35,843
7	2027	38,435	52,639	88	119	26,489	35,267	47,483	64,660

8	2028	59,297	81,407	135	184	40,901	54,617	73,172	99,861
9	2029	82,298	113,219	187	255	56,807	76,052	101,453	138,721
10	2030	107,120	147,615	244	332	73,983	99,254	131,946	180,693
11	2031	133,301	183,979	303	414	92,113	123,815	164,071	225,006
12	2032	160,323	221,578	364	498	110,838	149,236	197,201	270,780
13	2033	187,705	259,747	426	583	129,824	175,070	230,740	317,200
14	2034	215,016	297,890	487	668	148,774	200,913	264,162	363,538
15	2035	241,740	335,287	547	751	167,329	226,278	296,835	408,920
16	2036	267,285	371,100	604	830	185,076	250,595	328,037	452,334
17	2037	291,245	404,757	658	905	201,734	273,474	357,275	493,090
18	2038	313,236	435,712	707	973	217,033	294,540	384,081	530,530
19	2039	332,795	463,323	751	1034	230,655	313,361	407,891	563,873
20	2040	349,914	487,561	789	1087	242,589	329,909	428,697	593,093
21	2041	364,537	508,334	822	1133	252,796	344,118	446,443	618,091
22	2042	376,634	525,575	849	1170	261,248	355,931	461,098	638,799
23	2043	386,700	539,967	871	1202	268,289	365,810	473,272	656,055
24	2044	395,043	551,916	889	1228	274,129	374,020	483,353	670,368
25	2045	401,894	561,737	904	1249	278,926	380,771	491,628	682,127
26	2046	407,693	570,046	917	1267	282,986	386,481	498,635	692,077
27	2047	412,792	577,334	928	1283	286,552	391,483	504,803	700,817
28	2048	417,288	583,743	938	1297	289,694	395,875	510,250	708,515
29	2049	421,325	589,488	947	1310	292,513	399,808	515,143	715,421
30	2050	424,901	594,569	955	1321	295,009	403,284	519,483	721,535
31	2051	427,851	598,770	962	1330	297,070	406,161	523,059	726,583
32	2052	430,451	602,479	968	1338	298,887	408,704	526,205	731,035
33	2053	432,589	605,536	972	1345	300,383	410,802	528,791	734,700
34	2054	434,408	608,143	976	1351	301,657	412,594	530,990	737,823
35	2055	435,932	610,326	980	1355	302,723	414,094	532,831	740,437
36	2056	437,215	612,165	983	1359	303,621	415,358	534,380	742,639
37	2057	438,146	613,512	985	1362	304,275	416,288	535,499	744,243
38	2058	438,648	614,261	986	1364	304,632	416,815	536,094	745,121
39	2059	438,975	614,765	986	1365	304,867	417,174	536,474	745,701
40	2060	439,138	615,028	987	1365	304,986	417,366	536,657	745,996

Figure V-11 uses annual crash benefits as an example to depict the range of the annual benefits by years. The two curves represent the low and high bounds of the annual benefit estimates, respectively. Annual benefits for fatalities, MAIS 1-5 injuries, and PDOVs follow the same patterns.

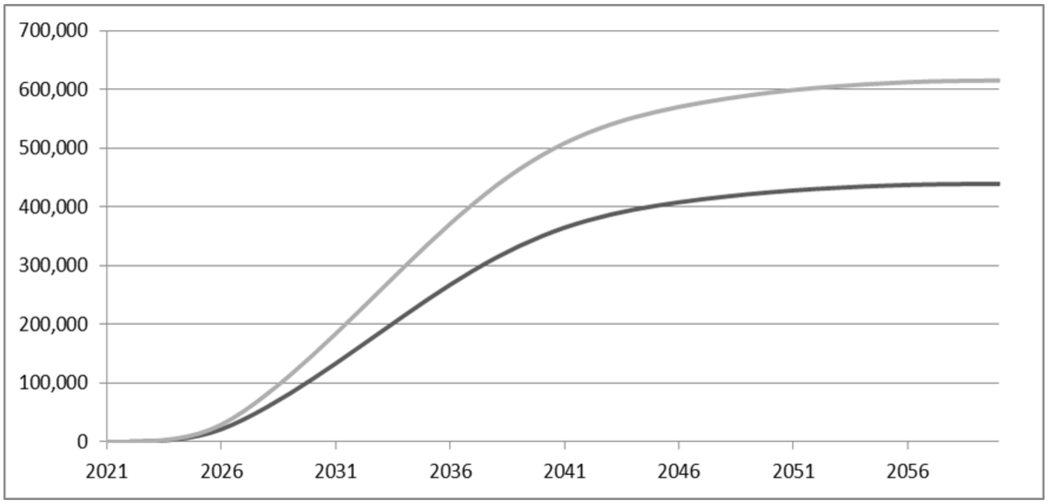


Figure V-11
Range of Annual Crash Benefits by Year

Tables V-15 and V-16 show the annual benefits for IMA and LTA, respectively. In 2060, undiscounted, IMA would prevent up to 431,619 crashes, save 1,021 lives, and reduce up to 280,479 MAIS 1-5 injuries annually. The IMA benefits would comprise 70 to 83 percent of the annual benefits of the proposed rule. The remaining 17 to 30 percent of the annual benefits would be from LTA. Within the same period, LTA would prevent 183,409 crashes, save 344 lives, and reduce 136,977 MAIS 1-5 injuries, annually. The disparity between the IMA and LTA benefits primarily is due to that IMA has a target population that is 2.1 to 3.3 times LTA. In addition, IMA has crashworthiness benefits but LTA does not.

Table V-15
Annual Benefits from IMA
(Undiscounted)

	Calendar	Crash Prevented		Fatalities Eliminated		MAIS 1-5 Injuries		PDOVs	
Year	Year	Low	High	Low	High	Low	High	Low	High
1	2021	0	0	0	0	0	0	0	0
2	2022	133	173	0	0	90	112	168	218
3	2023	862	1,122	2	3	584	729	1,089	1,419
4	2024	3,380	4,403	8	10	2,291	2,861	4,274	5,566
5	2025	8,551	11,136	20	26	5,794	7,236	10,811	14,080
6	2026	17,930	23,351	42	55	12,150	15,174	22,670	29,523
7	2027	31,982	41,651	76	99	21,673	27,066	40,437	52,662
8	2028	48,851	63,621	116	150	33,105	41,343	61,765	80,439
9	2029	67,212	87,532	159	207	45,547	56,881	84,980	110,672
10	2030	86,865	113,127	205	268	58,866	73,514	109,829	143,033

11	2031	107,380	139,845	254	331	72,768	90,875	135,767	176,813
12	2032	128,392	167,209	304	396	87,007	108,658	162,333	211,411
13	2033	149,504	194,703	354	461	101,313	126,524	189,026	246,173
14	2034	170,384	221,895	403	525	115,463	144,194	215,425	280,554
15	2035	190,633	248,267	451	587	129,185	161,332	241,028	313,897
16	2036	209,823	273,258	496	646	142,189	177,571	265,290	345,494
17	2037	227,653	296,479	539	701	154,272	192,661	287,834	374,854
18	2038	243,860	317,585	577	751	165,255	206,376	308,324	401,539
19	2039	258,078	336,102	611	795	174,890	218,409	326,301	424,951
20	2040	270,340	352,072	640	833	183,200	228,787	341,805	445,142
21	2041	280,647	365,495	664	865	190,185	237,510	354,837	462,114
22	2042	289,032	376,415	684	890	195,867	244,606	365,439	475,921
23	2043	295,893	385,349	700	912	200,516	250,412	374,113	487,217
24	2044	301,527	392,687	713	929	204,334	255,180	381,236	496,494
25	2045	306,134	398,686	724	943	207,456	259,078	387,061	504,080
26	2046	310,044	403,780	733	955	210,106	262,388	392,005	510,519
27	2047	313,524	408,312	742	966	212,464	265,333	396,405	516,249
28	2048	316,640	412,369	749	975	214,575	267,970	400,344	521,379
29	2049	319,457	416,038	756	984	216,484	270,354	403,906	526,018
30	2050	321,976	419,318	762	992	218,191	272,485	407,091	530,165
31	2051	324,030	421,994	767	998	219,584	274,224	409,689	533,548
32	2052	325,820	424,325	771	1004	220,796	275,739	411,951	536,495
33	2053	327,278	426,224	774	1008	221,785	276,973	413,795	538,897
34	2054	328,504	427,821	777	1012	222,616	278,011	415,346	540,916
35	2055	329,532	429,159	780	1015	223,312	278,880	416,645	542,607
36	2056	330,394	430,281	782	1018	223,896	279,610	417,734	544,026
37	2057	330,990	431,058	783	1020	224,300	280,114	418,488	545,009
38	2058	331,255	431,403	784	1020	224,480	280,339	418,823	545,445
39	2059	331,388	431,576	784	1021	224,570	280,451	418,991	545,663
40	2060	331,421	431,619	784	1021	224,592	280,479	419,033	545,718

Table V-16
Annual Benefits from LTA
(Undiscounted)

	Calendar	Crash Prevented		Fatalities Eliminated		MAIS 1-5 Injuries		PDOVs	
Year	Year	Low	High	Low	High	Low	High	Low	High
1	2021	0	0	0	0	0	0	0	0
2	2022	22	37	0	0	16	27	24	40
3	2023	151	257	0	0	113	192	165	281
4	2024	594	1,011	1	2	443	754	648	1,104
5	2025	1,543	2,627	3	5	1,152	1,961	1,685	2,869
6	2026	3,399	5,788	6	11	2,537	4,320	3,712	6,320
7	2027	6,453	10,988	12	21	4,816	8,201	7,047	11,998
8	2028	10,446	17,786	20	33	7,796	13,275	11,407	19,422
9	2029	15,086	25,687	28	48	11,259	19,171	16,473	28,049
10	2030	20,255	34,488	38	65	15,117	25,740	22,118	37,660
11	2031	25,920	44,134	49	83	19,345	32,940	28,304	48,193

12	2032	31,931	54,369	60	102	23,831	40,578	34,868	59,369
13	2033	38,200	65,044	72	122	28,511	48,545	41,714	71,026
14	2034	44,632	75,995	84	143	33,311	56,719	48,737	82,984
15	2035	51,107	87,019	96	163	38,143	64,947	55,807	95,023
16	2036	57,463	97,842	108	184	42,887	73,024	62,748	106,840
17	2037	63,592	108,278	120	203	47,462	80,813	69,441	118,237
18	2038	69,376	118,126	131	222	51,779	88,163	75,757	128,991
19	2039	74,718	127,222	141	239	55,765	94,952	81,590	138,922
20	2040	79,574	135,490	150	254	59,389	101,123	86,892	147,951
21	2041	83,890	142,839	158	268	62,611	106,608	91,606	155,977
22	2042	87,602	149,160	165	280	65,382	111,325	95,659	162,879
23	2043	90,807	154,617	171	290	67,774	115,398	99,159	168,838
24	2044	93,516	159,229	176	299	69,795	118,840	102,117	173,874
25	2045	95,760	163,051	180	306	71,470	121,693	104,568	178,047
26	2046	97,649	166,266	184	312	72,880	124,093	106,630	181,558
27	2047	99,267	169,022	187	317	74,088	126,150	108,397	184,568
28	2048	100,649	171,374	189	322	75,119	127,905	109,906	187,136
29	2049	101,868	173,451	192	326	76,029	129,454	111,237	189,403
30	2050	102,926	175,251	194	329	76,818	130,798	112,392	191,369
31	2051	103,821	176,776	195	332	77,487	131,937	113,370	193,035
32	2052	104,631	178,154	197	335	78,091	132,965	114,254	194,540
33	2053	105,310	179,312	198	337	78,598	133,829	114,996	195,804
34	2054	105,904	180,322	199	339	79,041	134,583	115,644	196,907
35	2055	106,400	181,168	200	340	79,411	135,214	116,186	197,830
36	2056	106,821	181,884	201	342	79,726	135,749	116,646	198,613
37	2057	107,156	182,454	202	343	79,975	136,174	117,011	199,235
38	2058	107,393	182,858	202	343	80,152	136,476	117,270	199,676
39	2059	107,587	183,189	202	344	80,297	136,723	117,482	200,037
40	2060	107,717	183,409	203	344	80,394	136,887	117,624	200,278

Separated by vehicle type, Tables V-17 and V-18 present the estimated annual benefits for PCs and LTVs, respectively. We note that these annual benefits will be used later in the PRIA to derive the lifetime benefits of vehicles sold in a particular model year (MY). As shown in the tables, from 2021 and 2060, undiscounted, the proposed rule for PCs would prevent up to 297,256 crashes, save up to 660 lives, and reduce up to 201,723 MAIS 1-5 injuries annually. Whereas, LTVs would prevent up to 317,772 crashes, save up to 705 lives, and reduce up to 215,644 MAIS 1-5 injuries, annually.

Table V-17
Annual Benefits for PCs
(Undiscounted)

	Calendar	Crash Prevented		Fatalities Eliminated		MAIS 1-5 Injuries		PDOVs	
Year	Year	Low	High	Low	High	Low	High	Low	High
1	2021	0	0	0	0	0	0	0	0
2	2022	77	105	0	0	53	70	96	129
3	2023	506	690	1	2	348	461	627	850
4	2024	2,026	2,759	5	6	1,393	1,842	2,509	3,400
5	2025	5,163	7,039	12	16	3,553	4,703	6,391	8,668
6	2026	10,918	14,914	25	34	7,518	9,977	13,504	18,347
7	2027	19,674	26,944	45	61	13,559	18,052	24,306	33,098
8	2028	30,375	41,701	69	94	20,951	27,978	37,482	51,153
9	2029	42,205	58,063	96	131	29,132	39,002	52,028	71,140
10	2030	54,968	75,747	125	171	37,964	50,930	67,708	92,721
11	2031	68,421	94,433	155	212	47,280	63,552	84,214	115,492
12	2032	82,355	113,821	187	256	56,936	76,660	101,299	139,095
13	2033	96,496	133,533	219	300	66,741	90,001	118,620	163,068
14	2034	110,668	153,325	251	344	76,574	103,411	135,963	187,113
15	2035	124,607	172,826	282	387	86,251	116,636	153,007	210,781
16	2036	138,017	191,625	312	429	95,567	129,400	169,387	233,571
17	2037	150,645	209,358	340	468	104,346	141,453	184,799	255,048
18	2038	162,283	225,737	366	504	112,442	152,598	198,987	274,861
19	2039	172,656	240,373	390	536	119,665	162,572	211,616	292,540
20	2040	181,709	253,188	410	565	125,976	171,320	222,622	307,991
21	2041	189,367	264,063	427	588	131,320	178,757	231,915	321,079
22	2042	195,123	272,287	440	606	135,345	184,399	238,881	330,944
23	2043	199,716	278,873	450	621	138,562	188,927	244,428	338,828
24	2044	203,256	283,971	458	632	141,044	192,440	248,692	344,916
25	2045	205,929	287,832	463	640	142,920	195,106	251,908	349,519
26	2046	207,966	290,783	468	646	144,352	197,146	254,356	353,032
27	2047	209,620	293,175	471	652	145,514	198,797	256,345	355,881
28	2048	210,912	295,044	474	656	146,422	200,088	257,899	358,108
29	2049	211,953	296,550	477	659	147,153	201,129	259,149	359,902
30	2050	212,785	297,755	478	662	147,737	201,962	260,150	361,337
31	2051	213,333	298,554	480	663	148,123	202,517	260,805	362,284
32	2052	213,715	299,126	480	664	148,395	202,918	261,256	362,953
33	2053	213,867	299,371	481	665	148,506	203,097	261,428	363,228
34	2054	213,920	299,475	481	665	148,548	203,179	261,480	363,334
35	2055	213,864	299,419	481	665	148,513	203,149	261,402	363,250
36	2056	213,720	299,240	480	664	148,417	203,037	261,216	363,018
37	2057	213,433	298,858	480	664	148,221	202,785	260,857	362,541
38	2058	213,025	298,309	479	662	147,941	202,421	260,349	361,860
39	2059	212,617	297,761	478	661	147,662	202,058	259,841	361,180
40	2060	212,243	297,256	477	660	147,405	201,723	259,375	360,554

Table V-18
Annual Benefits for LTVs
(Undiscounted)

	Calendar	Crash Prevented		Fatalities Eliminated		MAIS 1-5 Injuries		PDOVs	
Year	Year	Low	High	Low	High	Low	High	Low	High
1	2021	0	0	0	0	0	0	0	0
2	2022	77	105	0	0	53	70	96	129
3	2023	506	690	1	2	348	461	627	850
4	2024	1,948	2,654	4	6	1,340	1,773	2,413	3,270
5	2025	4,931	6,725	11	15	3,394	4,494	6,105	8,281
6	2026	10,411	14,224	24	32	7,170	9,517	12,877	17,497
7	2027	18,761	25,694	43	58	12,930	17,215	23,177	31,562
8	2028	28,923	39,706	66	90	19,950	26,639	35,690	48,707
9	2029	40,093	55,157	91	124	27,674	37,050	49,425	67,580
10	2030	52,152	71,868	119	162	36,019	48,323	64,239	87,972
11	2031	64,880	89,546	147	201	44,833	60,263	79,857	109,514
12	2032	77,968	107,757	177	242	53,903	72,576	95,902	131,685
13	2033	91,208	126,214	207	283	63,083	85,068	112,120	154,131
14	2034	104,347	144,566	236	324	72,200	97,502	128,198	176,425
15	2035	117,133	162,461	265	364	81,077	109,642	143,828	198,138
16	2036	129,268	179,475	292	401	89,509	121,195	158,651	218,763
17	2037	140,600	195,399	318	437	97,388	132,021	172,476	238,042
18	2038	150,953	209,975	341	469	104,591	141,942	185,095	255,670
19	2039	160,139	222,950	361	498	110,990	150,789	196,275	271,333
20	2040	168,205	234,374	379	523	116,614	158,590	206,076	285,103
21	2041	175,171	244,271	395	544	121,476	165,360	214,528	297,011
22	2042	181,511	253,289	409	564	125,903	171,532	222,217	307,855
23	2043	186,983	261,094	421	581	129,728	176,883	228,844	317,226
24	2044	191,787	267,946	432	596	133,085	181,580	234,660	325,452
25	2045	195,965	273,905	441	609	136,005	185,666	239,720	332,608
26	2046	199,727	279,263	449	621	138,633	189,335	244,280	339,046
27	2047	203,172	284,159	457	632	141,038	192,685	248,458	344,936
28	2048	206,376	288,699	464	642	143,272	195,786	252,351	350,407
29	2049	209,372	292,938	471	651	145,360	198,679	255,994	355,519
30	2050	212,116	296,814	477	659	147,272	201,322	259,333	360,197
31	2051	214,519	300,216	482	667	148,947	203,644	262,254	364,299
32	2052	216,736	303,353	487	674	150,492	205,786	264,949	368,082
33	2053	218,722	306,165	492	680	151,877	207,705	267,363	371,472
34	2054	220,488	308,668	496	686	153,109	209,415	269,510	374,489
35	2055	222,068	310,908	499	690	154,211	210,945	271,429	377,187
36	2056	223,495	312,925	502	695	155,205	212,322	273,164	379,621
37	2057	224,713	314,654	505	699	156,055	213,504	274,643	381,702
38	2058	225,623	315,952	507	702	156,691	214,393	275,745	383,261
39	2059	226,358	317,003	509	704	157,205	215,116	276,633	384,521
40	2060	226,895	317,772	510	705	157,581	215,644	277,282	385,442

F. Lifetime Benefits for A Model Year of Vehicles (i.e., MY Benefits)

The MY benefits represent the total benefits that would be accrued though the life of a vehicle. The lifetime benefits can occur at any time during the in-use life of a vehicle and are required to be discounted to reflect their present values (2014 dollars). The discounting procedures for future benefits and costs in regulatory analyses are based on the guidelines published in OMB Circular A-4 and OMB Circular A-94 Revised. Discount rates are 3 and 7 percent. For example, passenger cars (PCs) have a lifespan of 30 years and the MY 2030 PCs will be on the road from 2030 to 2059. During that time, the MY 2030 vehicles will communicate with an increasing percentage of later model years of vehicles that have V2V. Each of those year, the MY 2030 vehicles are expected to accrue some benefits. These annual benefits are discounted back to the year the vehicle was purchased. The estimated lifetime benefits for MY 2030 vehicles thus are the accumulation of these discounted benefits over their lifetime.

The analysis used two approaches to estimate the MY benefits. One is so called "free rider" approach and the other is the "no free-rider" approach. Basically, these two approach deployed a different treatment on the distribution of benefits from crashes involving different MY vehicles. The free-rider approach is based on the notion that the lifetime benefits of MY vehicles should correspond to the investment up to that specific MY vehicles and that benefits should be credited to the later MY vehicles. For example, if benefits are from a crash that involved a MY 2021 vehicle and a MY 2030 vehicle, under this approach, all these benefits would be credited to the MY 2030 vehicle. The MY 2021 vehicles would not receive any of these benefits since these benefits would not be realized until the investment on the MY 2030 vehicles is made.

In contrast, the "no free-rider" approach is based on the notion that benefits should be shared among all MY vehicles since the future investment will continue because of the proposed rule. With the same case above, the no free-rider approach allows both MY 2021 and MY 2030 vehicles to share a portion of the benefits.

Under both approaches, the MY benefits were derived by dividing the annual benefits among all involved MY vehicles according to their survived volume and vehicle miles traveled. Afterwards, the annual benefits for that specific MY vehicles were discounted by multiplying them with an appropriate discounting factor. Finally, we summed the annual discounted benefits of that MY vehicles over their operational lifespan to derive the MY benefits. The process is expressed below:

$$\sum_{j=1}^{L} B_{i+j-1}^{MY} = AB_i * F_{i+j-1}^{MY} * d_{i+j-1}^{MY}$$

Where,

j = age of the MY vehicles at year i, i.e., i+j-1=MY when j=1

B_{i+j-1}^{MY} = benefit for the MY vehicles at age j for year i

AB_i = annual benefit of the proposed rule at year i

F_{i+j-1}^{MY} = distribution factor for this MY vehicles at age j for year i

d_{i-j+1}^{MY} = discount factor for this MY vehicles at age j for year i

L = lifespan of the vehicle type of the MY vehicles.

Based on the estimate, the lifespan is 30 years for PCs and 37 year for LTVs. Therefore, L=30 for PCs and L=37 for LTVs. Since PCs and LTVs have two different lifespans, the MY benefits were estimated separately for PCs and LTVs. Combing together, they represent the lifetime benefits for vehicles sold in a particular model year. As discussed above, the methodology used for annual benefits (AB_i) was discussed in the annual benefits section. The following two sub-sections describe the distribution (F_{i+j-1}^{MY}) and discounting (d_{i+j-1}^{MY}) factors, respectively.

F.1 Distribution Factors Among MY Vehicles (F_{i+j-1}^{MY})

The distribution of an annual benefit among MY vehicles depends on the communication rates and vehicle miles traveled (VMT) for MY vehicles in a particular year. For a specific MY vehicles, F_{i+j-1}^{MY} is its relative communication rates to the overall communication rates weighted by its relative vehicle miles travel to the first year VMT. The communication rates were calculated separately for the "free-rider" and "no free-rider" approaches. For the "free rider" approach, the communication rate for a MY vehicles is the communication among vehicles only up to that MY since this approach credits the benefits from the interaction between two different MY vehicles to the newer MY vehicles. For "no free-rider" approach, since the benefits are shared among all vehicles involved, the communication rate for a MY vehicle would be the sum of these rates: (1) the communication rate among this MY vehicles and (2) the communication rate between this MY and other MY vehicles.

Tables V-19 and V-20 present a portion of the distribution factors for the "free-rider" and "no free-rider" approaches, respectively. For PCs, in year 2023, for example, the free-rider approach credits 7 percent of the annual benefits to MY 2022 vehicles and the remaining 93 percent to MY 2023 vehicles. In contrast, for the no free-rider approach, 26 percent would be credited to MY 2022 vehicles and 74 percent to MY 2023 vehicles. Note that the distribution for PCs and LTVs are similar because it generally reflects the relative proportion of each MY vehicles within a vehicle type. For a particular vehicle type, MY vehicles follow the same scrappage rates and thus would not disturb the relative proportion that is inherently in the PCs and LTVs.

Table V-19
Annual Benefit Distribution Factors for 2021 to 2035
Free-Rider Approach

PCs

	Model Year														
CY	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**
2021	0.00														
2022	0.00	1.00													
2023	0.00	0.07	0.93												
2024	0.00	0.01	0.11	0.88											
2025	0.00	0.00	0.02	0.20	0.77										
2026	0.00	0.00	0.01	0.06	0.22	0.72									
2027	0.00	0.00	0.00	0.02	0.08	0.25	0.65								
2028	0.00	0.00	0.00	0.01	0.04	0.12	0.30	0.54							
2029	0.00	0.00	0.00	0.01	0.02	0.07	0.17	0.30	0.44						
2030	0.00	0.00	0.00	0.00	0.01	0.04	0.10	0.19	0.27	0.37					
2031	0.00	0.00	0.00	0.00	0.01	0.03	0.07	0.13	0.19	0.25	0.33				
2032	0.00	0.00	0.00	0.00	0.00	0.02	0.05	0.09	0.13	0.18	0.23	0.29			
2033	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.07	0.10	0.13	0.17	0.22	0.27		
2034	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.05	0.07	0.10	0.13	0.17	0.20	0.25	
2035	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.05	0.08	0.10	0.13	0.16	0.19	0.23

LTVs

CY	Model Year														
	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
2021	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2022	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2023	0.00	0.07	0.93	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2024	0.00	0.01	0.11	0.89	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2025	0.00	0.00	0.02	0.19	0.78	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2026	0.00	0.00	0.01	0.05	0.21	0.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2027	0.00	0.00	0.00	0.02	0.07	0.25	0.66	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2028	0.00	0.00	0.00	0.01	0.03	0.11	0.29	0.55	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2029	0.00	0.00	0.00	0.00	0.02	0.06	0.16	0.30	0.45	0.00	0.00	0.00	0.00	0.00	0.00
2030	0.00	0.00	0.00	0.00	0.01	0.04	0.10	0.19	0.28	0.39	0.00	0.00	0.00	0.00	0.00
2031	0.00	0.00	0.00	0.00	0.01	0.03	0.07	0.12	0.18	0.25	0.34	0.00	0.00	0.00	0.00
2032	0.00	0.00	0.00	0.00	0.00	0.02	0.05	0.09	0.13	0.18	0.24	0.30	0.00	0.00	0.00
2033	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.06	0.09	0.13	0.17	0.22	0.28	0.00	0.00
2034	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.04	0.07	0.10	0.13	0.16	0.21	0.26	0.00
2035	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.05	0.07	0.10	0.13	0.16	0.20	0.24

CY: calendar year

Table V-20
Annual Benefit Distribution Factors for 2021 to 2035
No Free-Rider Approach

PCs

	Model Year														
CY	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**
2021	0.00	0.00													
2022	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2023	0.00	0.26	0.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2024	0.00	0.09	0.25	0.66	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2025	0.00	0.04	0.12	0.31	0.52	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2026	0.00	0.02	0.06	0.17	0.28	0.47	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2027	0.00	0.01	0.04	0.10	0.17	0.28	0.41	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2028	0.00	0.01	0.03	0.07	0.11	0.19	0.27	0.32	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2029	0.00	0.01	0.02	0.05	0.08	0.14	0.21	0.24	0.25	0.00	0.00	0.00	0.00	0.00	0.00
2030	0.00	0.00	0.01	0.04	0.07	0.11	0.16	0.19	0.20	0.21	0.00	0.00	0.00	0.00	0.00
2031	0.00	0.00	0.01	0.03	0.05	0.09	0.13	0.16	0.17	0.17	0.18	0.00	0.00	0.00	0.00
2032	0.00	0.00	0.01	0.02	0.04	0.08	0.11	0.13	0.14	0.15	0.15	0.16	0.00	0.00	0.00
2033	0.00	0.00	0.01	0.02	0.04	0.06	0.10	0.11	0.12	0.13	0.13	0.14	0.14	0.00	0.00
2034	0.00	0.00	0.01	0.02	0.03	0.05	0.08	0.10	0.11	0.11	0.12	0.12	0.13	0.13	0.00
2035	0.00	0.00	0.01	0.02	0.03	0.05	0.07	0.08	0.09	0.10	0.10	0.11	0.11	0.12	0.12

LTVs

	Model Year														
CY	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**
2021	0.00	0.00													
2022	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2023	0.00	0.26	0.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2024	0.00	0.09	0.25	0.66	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2025	0.00	0.04	0.12	0.31	0.53	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2026	0.00	0.02	0.06	0.16	0.28	0.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2027	0.00	0.01	0.04	0.10	0.16	0.28	0.41	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2028	0.00	0.01	0.02	0.07	0.11	0.19	0.28	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2029	0.00	0.01	0.02	0.05	0.08	0.14	0.20	0.24	0.26	0.00	0.00	0.00	0.00	0.00	0.00
2030	0.00	0.00	0.01	0.04	0.07	0.11	0.16	0.19	0.20	0.22	0.00	0.00	0.00	0.00	0.00
2031	0.00	0.00	0.01	0.03	0.05	0.09	0.13	0.16	0.16	0.17	0.19	0.00	0.00	0.00	0.00
2032	0.00	0.00	0.01	0.02	0.04	0.07	0.11	0.13	0.14	0.15	0.16	0.17	0.00	0.00	0.00
2033	0.00	0.00	0.01	0.02	0.04	0.06	0.09	0.11	0.12	0.13	0.13	0.14	0.15	0.00	0.00
2034	0.00	0.00	0.01	0.02	0.03	0.05	0.08	0.09	0.10	0.11	0.12	0.12	0.13	0.14	0.00
2035	0.00	0.00	0.00	0.01	0.02	0.04	0.07	0.08	0.09	0.10	0.10	0.11	0.11	0.12	0.13

CY: calendar year

F.2 Discount Factors (d^{MY}_{i+j-1})

The discount factors are used to discount the MY benefit to reflect its present value. Generally, the discount factors need to take into account the vehicle survivability and VMT. However, vehicle survivability was already considered when the annual benefit estimates were established. Therefore, the discounted factors established here are VMT-weighted discount factors. The VMT weighting factors are the ratio of the remaining lifetime VMTs for a MY vehicles at year i to its total lifetime VMT. The raw discount factors are the mid-year discount factors. Therefore, d^{MY}_{i} can be further expanded as in the following formula:

$$d^{MY}_{i+j-1} = d_j * \frac{\sum_{i-MY+1}^{L} VMT_j}{\sum_{j=1}^{L} VMT_j}$$

Where,

j = age of the MY vehicles at year i, i.e., $i+j-1=MY$ when $j=1$

d^{MY}_{i+j-1} = discount factor at age j for year i

d_j = mid-year raw discount factor at age j

VMT_j = vehicle miles traveled at age j

L = lifespan of this vehicle type, L=30 years for PCs and 37 years for LTVs.

The summation $\sum_{i=1}^{L} VMT_i$ in the above formula represents the total average lifetime VMT for a MY vehicles and $\sum_{L-i+1}^{L} VMT_i$ represents the remaining total VMT for age j vehicles. Thus, $\frac{\sum_{i-MY+1}^{L} VMT_j}{\sum_{j=1}^{L} VMT_j}$ representing the ratio of the remaining total VMT to the total lifetime VMT is called VMT factor. This factor then is applied to the mid-year raw factor, d_i, to derive the VMT-weighted discount factors and $d_i = \frac{1}{(1+r)^{age-0.5}}$, where r is either 3 or 7 percent. Tables V-21 and V-22 show the process of deriving the VMT-weighted discount factors for the 3 and 7 percent discount, respectively. VMT was the projected 2021 level. The detailed projection process is discussed in Appendix A.

Table V-21
Discount Factors **@3 Percent**

Age	VMT (a)		VMT Factor (b)		Raw Discount Factor (c)	VMT Weighted Discount Factor (d)	
	Cars	LTVs	Cars	LTVs		Cars	LTVs
1	14,857	16,145	1.0000	1.0000	0.9853	0.9853	0.9853
2	14,405	15,569	0.9512	0.9559	0.9566	0.9099	0.9145
3	14,175	15,000	0.9038	0.9135	0.9288	0.8395	0.8484
4	13,738	14,589	0.8573	0.8725	0.9017	0.7730	0.7868
5	13,467	14,187	0.8121	0.8327	0.8755	0.7110	0.7291
6	13,203	13,797	0.7679	0.7940	0.8500	0.6527	0.6749
7	12,946	12,726	0.7245	0.7564	0.8252	0.5979	0.6242
8	11,499	12,324	0.6820	0.7217	0.8012	0.5464	0.5782
9	11,206	11,937	0.6442	0.6881	0.7778	0.5010	0.5352
10	10,923	11,565	0.6074	0.6555	0.7552	0.4587	0.4950
11	10,648	11,210	0.5715	0.6239	0.7332	0.4190	0.4575
12	10,382	10,871	0.5365	0.5933	0.7118	0.3819	0.4223
13	10,127	10,546	0.5024	0.5637	0.6911	0.3472	0.3896
14	9,885	10,238	0.4691	0.5349	0.6710	0.3148	0.3589
15	9,651	9,944	0.4366	0.5070	0.6514	0.2844	0.3302
16	9,423	9,668	0.4049	0.4798	0.6324	0.2561	0.3035
17	9,210	9,404	0.3739	0.4535	0.6140	0.2296	0.2784
18	9,003	9,160	0.3437	0.4278	0.5961	0.2049	0.2550
19	8,807	8,928	0.3141	0.4028	0.5788	0.1818	0.2332
20	8,622	8,711	0.2852	0.3785	0.5619	0.1602	0.2127
21	8,446	8,513	0.2568	0.3547	0.5456	0.1401	0.1935
22	8,278	8,328	0.2291	0.3315	0.5297	0.1213	0.1756
23	8,124	8,162	0.2019	0.3087	0.5142	0.1038	0.1588
24	7,975	8,007	0.1752	0.2865	0.4993	0.0875	0.1430
25	7,842	7,873	0.1490	0.2646	0.4847	0.0722	0.1283
26	7,712	7,748	0.1232	0.2431	0.4706	0.0580	0.1144
27	7,598	7,644	0.0978	0.2220	0.4569	0.0447	0.1014
28	7,489	7,554	0.0729	0.2012	0.4436	0.0323	0.0892
29	7,393	7,479	0.0483	0.1805	0.4307	0.0208	0.0778
30	7,303	7,421	0.0240	0.1601	0.4181	0.0100	0.0670
31	0	7,376	0.0000	0.1399	0.4059	0.0000	0.0568
32	0	7,347	0.0000	0.1198	0.3941	0.0000	0.0472
33	0	7,335	0.0000	0.0997	0.3826	0.0000	0.0382
34	0	7,323	0.0000	0.0797	0.3715	0.0000	0.0296
35	0	7,310	0.0000	0.0597	0.3607	0.0000	0.0215
36	0	7,298	0.0000	0.0398	0.3502	0.0000	0.0139
37	0	7,285	0.0000	0.0199	0.3400	0.0000	0.0068

Table V-22
Discount Factors **@7 Percent**

Age	VMT (a)		VMT Factor (b)		Raw Discount Factor (c)	VMT Weighted Discount Factors (d)	
	Cars	**LTVs**	**Cars**	**LTVs**		**Cars**	**LTVs**
1	14,857	16,145	1.0000	1.0000	0.9667	0.9667	0.9667
2	14,405	15,569	0.9512	0.9559	0.9035	0.8594	0.8637
3	14,175	15,000	0.9038	0.9135	0.8444	0.7632	0.7713
4	13,738	14,589	0.8573	0.8725	0.7891	0.6765	0.6885
5	13,467	14,187	0.8121	0.8327	0.7375	0.5989	0.6141
6	13,203	13,797	0.7679	0.7940	0.6893	0.5293	0.5473
7	12,946	12,726	0.7245	0.7564	0.6442	0.4667	0.4873
8	11,499	12,324	0.6820	0.7217	0.6020	0.4105	0.4344
9	11,206	11,937	0.6442	0.6881	0.5626	0.3624	0.3871
10	10,923	11,565	0.6074	0.6555	0.5258	0.3193	0.3447
11	10,648	11,210	0.5715	0.6239	0.4914	0.2808	0.3066
12	10,382	10,871	0.5365	0.5933	0.4593	0.2464	0.2725
13	10,127	10,546	0.5024	0.5637	0.4292	0.2156	0.2419
14	9,885	10,238	0.4691	0.5349	0.4012	0.1882	0.2146
15	9,651	9,944	0.4366	0.5070	0.3749	0.1637	0.1901
16	9,423	9,668	0.4049	0.4798	0.3504	0.1419	0.1681
17	9,210	9,404	0.3739	0.4535	0.3275	0.1225	0.1485
18	9,003	9,160	0.3437	0.4278	0.3060	0.1052	0.1309
19	8,807	8,928	0.3141	0.4028	0.2860	0.0898	0.1152
20	8,622	8,711	0.2852	0.3785	0.2673	0.0762	0.1012
21	8,446	8,513	0.2568	0.3547	0.2498	0.0642	0.0886
22	8,278	8,328	0.2291	0.3315	0.2335	0.0535	0.0774
23	8,124	8,162	0.2019	0.3087	0.2182	0.0440	0.0674
24	7,975	8,007	0.1752	0.2865	0.2039	0.0357	0.0584
25	7,842	7,873	0.1490	0.2646	0.1906	0.0284	0.0504
26	7,712	7,748	0.1232	0.2431	0.1781	0.0219	0.0433
27	7,598	7,644	0.0978	0.2220	0.1665	0.0163	0.0370
28	7,489	7,554	0.0729	0.2012	0.1556	0.0113	0.0313
29	7,393	7,479	0.0483	0.1805	0.1454	0.0070	0.0263
30	7,303	7,421	0.0240	0.1601	0.1359	0.0033	0.0218
31	0	7,376	0.0000	0.1399	0.1270	0.0000	0.0178
32	0	7,347	0.0000	0.1198	0.1187	0.0000	0.0142
33	0	7,335	0.0000	0.0997	0.1109	0.0000	0.0111
34	0	7,323	0.0000	0.0797	0.1037	0.0000	0.0083
35	0	7,310	0.0000	0.0597	0.0969	0.0000	0.0058
36	0	7,298	0.0000	0.0398	0.0905	0.0000	0.0036
37	0	7,285	0.0000	0.0199	0.0846	0.0000	0.0017

F.3 MY Benefits

The above two sections established the MY distribution factors and VMT-weighted discount factors for both “free-rider” and “no free-rider” approaches. Applying these two factors to the corresponding annual benefits (Tables V-12) derives the MY benefits. The following two sub-sections discuss the MY benefits by this order (1) for all light vehicles (i.e., PCs and LTVs combined) and (2) by vehicles type. Each subsection starts with the benefits for “free-rider” then for “no free-rider”. The last sub-section summarizes the MY benefits that combine the “free rider’ and “no free-rider” approaches.

MY Benefits for All light Vehicles

Tables V-23 and V-24 show the MY benefits (i.e., the lifetime benefits for a MY vehicle’s) for the “free rider approach” for the 3 and 7 percent discount, respectively. In parallel, Tables V-25 and V-26 show the MY benefits for the “no free-rider” approach at a 3 and 7 percent discount rate, respectively. The analysis estimates the lifetime benefits only for MYs 2021 to 2050 vehicles. For 2050 MY vehicles, its lifetime benefits would be realized from year 2040 to year 2086. As described in the annual benefit section, the annual benefits would be stabilized at the maximum level around year 2062. Furthermore, after MY 2050, vehicle sales were assumed to at the MY 2050 level. Therefore, the lifetime benefits for vehicles newer than MY 2050 would be stabilized at the MY 2050 level.

Table V-23
MY Benefits for Light Vehicles
Free-Rider Approach
@3 Percent Discount

Year	Model Year	Crash Prevented		Fatalities Eliminated		MAIS 1-5 Injuries		PDOVs	
		Low	High	Low	High	Low	High	Low	High
1	2021	0	0	0	0	0	0	0	0
2	2022	271	369	1	1	187	246	336	455
3	2023	1,821	2,484	4	6	1,254	1,660	2,255	3,059
4	2024	8,138	11,116	19	25	5,604	7,436	10,066	13,675
5	2025	20,094	27,510	46	62	13,847	18,427	24,828	33,799
6	2026	45,766	62,828	104	142	31,567	42,151	56,477	77,072
7	2027	86,774	119,428	198	269	59,905	80,243	106,948	146,292
8	2028	125,283	172,790	285	389	86,552	116,237	154,257	211,408
9	2029	151,801	209,713	345	471	104,932	141,211	186,755	256,340
10	2030	175,685	243,053	398	545	121,501	163,794	215,991	296,855
11	2031	196,823	272,641	446	611	136,178	183,866	241,830	332,755
12	2032	215,458	298,792	488	669	149,129	201,633	264,580	364,439
13	2033	231,828	321,830	524	720	160,518	217,309	284,539	392,308
14	2034	247,041	343,282	558	767	171,108	231,922	303,068	418,229
15	2035	260,349	362,101	588	809	180,382	244,762	319,252	440,931
16	2036	271,907	378,496	614	845	188,445	255,966	333,289	460,676
17	2037	282,112	393,009	636	877	195,570	265,900	345,664	478,129
18	2038	290,458	404,930	655	903	201,406	274,078	355,763	492,430
19	2039	297,903	415,591	671	926	206,617	281,402	364,761	505,202
20	2040	305,087	425,875	687	948	211,645	288,466	373,446	517,525
21	2041	312,804	436,885	704	972	217,039	296,015	382,788	530,741
22	2042	305,604	427,030	688	950	212,077	289,414	373,891	518,632
23	2043	308,426	431,146	694	959	214,065	292,270	377,270	523,513
24	2044	310,949	434,815	699	967	215,841	294,812	380,294	527,871
25	2045	313,325	438,253	705	974	217,510	297,187	383,150	531,965
26	2046	315,443	441,309	709	981	218,996	299,295	385,700	535,611
27	2047	317,611	444,417	714	987	220,514	301,432	388,318	539,332
28	2048	319,665	447,353	719	994	221,951	303,447	390,802	542,853
29	2049	321,616	450,138	723	1,000	223,315	305,356	393,165	546,196
30	2050	323,726	453,138	728	1,006	224,788	307,409	395,724	549,803

Table V-24
MY Benefits for Light Vehicles
Free-Rider Approach
@7 Percent Discount

Year	Model Year	Crash Prevented		Fatalities Eliminated		MAIS 1-5 Injuries		PDOVs	
		Low	High	Low	High	Low	High	Low	High
1	2021	0	0	0	0	0	0	0	0
2	2022	256	348	1	1	176	232	317	429
3	2023	1,703	2,322	4	5	1,172	1,552	2,109	2,860
4	2024	7,517	10,264	17	23	5,175	6,865	9,300	12,630
5	2025	18,321	25,071	42	57	12,623	16,789	22,643	30,811
6	2026	41,157	56,470	94	128	28,383	37,874	50,801	69,294
7	2027	77,149	106,128	176	239	53,251	71,286	95,110	130,038
8	2028	110,525	152,362	251	343	76,343	102,466	136,116	186,464
9	2029	133,399	184,211	303	414	92,198	124,008	164,150	225,223
10	2030	154,035	213,015	349	478	106,513	143,518	189,411	260,228
11	2031	172,397	238,716	391	535	119,263	160,954	211,857	291,412
12	2032	188,544	261,378	427	585	130,486	176,350	231,570	318,868
13	2033	202,920	281,609	459	630	140,486	190,116	249,097	343,341
14	2034	216,257	300,416	489	672	149,771	202,927	265,341	366,065
15	2035	227,911	316,898	515	708	157,892	214,173	279,513	385,947
16	2036	238,068	331,308	537	740	164,978	224,022	291,846	403,300
17	2037	247,120	344,183	558	768	171,299	232,835	302,824	418,783
18	2038	254,424	354,622	574	791	176,407	239,999	311,659	431,301
19	2039	260,956	363,981	588	811	180,980	246,431	319,551	442,510
20	2040	267,247	372,995	602	831	185,384	252,625	327,152	453,305
21	2041	273,843	382,418	617	851	189,997	259,091	335,132	464,608
22	2042	267,553	373,820	602	832	185,665	253,336	327,356	454,035
23	2043	270,054	377,472	608	839	187,427	255,872	330,347	458,363
24	2044	272,178	380,572	612	846	188,924	258,023	332,888	462,038
25	2045	274,288	383,630	617	853	190,407	260,137	335,424	465,677
26	2046	276,078	386,219	621	858	191,664	261,926	337,576	468,762
27	2047	278,074	389,079	625	864	193,061	263,891	339,986	472,186
28	2048	279,772	391,511	629	870	194,250	265,562	342,038	475,099
29	2049	281,380	393,809	633	875	195,374	267,140	343,983	477,855
30	2050	283,192	396,388	637	880	196,640	268,906	346,180	480,956

Table V-25
MY Benefits for Light Vehicles
No Free-Rider Approach
@3 Percent Discount

Year	Model Year	Crash Prevented		Fatalities Eliminated		MAIS 1-5 Injuries		PDOVs	
		Low	High	Low	High	Low	High	Low	High
1	2021	0	0	0	0	0	0	0	0
2	2022	4,006	5,506	9	12	2,764	3,697	4,941	6,750
3	2023	12,297	16,917	28	38	8,488	11,363	15,159	20,727
4	2024	34,161	47,041	78	106	23,588	31,616	42,093	57,606
5	2025	59,813	82,461	136	186	41,316	55,459	73,659	100,913
6	2026	104,216	143,863	237	323	72,020	96,827	128,262	175,926
7	2027	153,676	212,415	349	477	106,247	143,074	189,014	259,566
8	2028	180,917	250,375	410	562	125,133	168,761	222,387	305,740
9	2029	190,032	263,281	430	590	131,488	177,573	233,465	321,299
10	2030	199,389	276,526	451	619	138,010	186,614	244,840	337,269
11	2031	207,808	288,476	470	645	143,885	194,784	255,061	351,656
12	2032	215,391	299,268	487	669	149,181	202,173	264,254	364,628
13	2033	222,098	308,843	502	690	153,870	208,741	272,371	376,118
14	2034	228,851	318,485	517	711	158,591	215,353	280,546	387,688
15	2035	234,712	326,883	530	729	162,695	221,125	287,627	397,746
16	2036	239,796	334,194	541	745	166,258	226,159	293,758	406,483
17	2037	244,444	340,890	551	760	169,518	230,774	299,356	414,478
18	2038	248,150	346,265	559	771	172,124	234,492	303,807	420,872
19	2039	251,493	351,122	566	782	174,475	237,855	307,817	426,644
20	2040	254,958	356,134	574	792	176,909	241,317	311,982	432,615
21	2041	258,973	361,900	583	805	179,722	245,284	316,828	439,511
22	2042	251,474	351,552	566	782	174,540	238,321	307,596	426,854
23	2043	252,797	353,515	569	786	175,478	239,695	309,167	429,160
24	2044	254,138	355,482	572	790	176,425	241,064	310,767	431,486
25	2045	255,409	357,336	574	794	177,320	242,350	312,289	433,684
26	2046	256,606	359,072	577	798	178,162	243,551	313,725	435,749
27	2047	257,844	360,856	580	802	179,030	244,781	315,217	437,879
28	2048	258,876	362,342	582	805	179,754	245,805	316,460	439,653
29	2049	259,929	363,853	584	808	180,492	246,844	317,732	441,462
30	2050	261,241	365,723	587	812	181,408	248,125	319,322	443,708

Table V-26
MY Benefits for Light Vehicles
No Free-Rider Approach
@7 Percent Discount

	Model	Crash Prevented		Fatalities Eliminated		MAIS 1-5 Injuries		PDOVs	
Year	Year	Low	High	Low	High	Low	High	Low	High
1	2021	0	0	0	0	0	0	0	0
2	2022	3,026	4,154	7	9	2,087	2,787	3,735	5,096
3	2023	9,423	12,946	21	29	6,501	8,689	11,624	15,874
4	2024	26,555	36,520	60	82	18,328	24,527	32,742	44,755
5	2025	46,855	64,517	107	145	32,352	43,361	57,736	79,010
6	2026	82,119	113,231	187	255	56,727	76,161	101,122	138,557
7	2027	121,940	168,381	277	378	84,277	113,350	150,052	205,873
8	2028	144,104	199,249	327	447	99,640	134,231	177,213	243,433
9	2029	152,069	210,514	345	472	105,191	141,918	186,899	257,022
10	2030	160,196	222,006	363	497	110,854	149,758	196,784	270,886
11	2031	167,621	232,533	379	521	116,033	156,950	205,804	283,568
12	2032	174,185	241,865	394	541	120,615	163,337	213,764	294,792
13	2033	180,128	250,340	407	559	124,769	169,145	220,962	304,969
14	2034	186,049	258,785	420	578	128,907	174,934	228,133	315,108
15	2035	191,219	266,186	432	594	132,525	180,018	234,382	323,976
16	2036	195,680	272,596	441	608	135,651	184,430	239,763	331,640
17	2037	199,807	278,538	450	621	138,545	188,523	244,737	338,737
18	2038	202,975	283,135	457	631	140,773	191,705	248,540	344,204
19	2039	205,888	287,369	464	640	142,823	194,636	252,034	349,234
20	2040	208,845	291,652	470	649	144,901	197,597	255,587	354,333
21	2041	212,188	296,460	478	660	147,244	200,908	259,617	360,079
22	2042	205,999	287,930	464	640	142,969	195,173	251,993	349,638
23	2043	207,175	289,675	466	644	143,803	196,394	253,389	351,688
24	2044	208,251	291,263	468	647	144,564	197,502	254,669	353,558
25	2045	209,421	292,967	471	651	145,388	198,684	256,071	355,582
26	2046	210,280	294,224	473	654	145,994	199,557	257,098	357,069
27	2047	211,429	295,876	475	657	146,799	200,694	258,483	359,043
28	2048	212,258	297,073	477	660	147,381	201,521	259,481	360,471
29	2049	213,224	298,458	479	663	148,057	202,472	260,648	362,129
30	2050	214,216	299,875	481	666	148,751	203,445	261,848	363,829

MY Benefits by Vehicle Type

The following eight tables, Tables V-27 to V-34, show the MY benefits by vehicle types. The first set of four tables is for the free-rider approach and the second set of four tables is for the no free-rider approach. The first two tables of each set are for the 3 percent discount rate and the last two tables are for the 7 percent discount rate.

Table V-27
MY Benefits for MY **PCs**
Free-Rider Approach
@3 Percent Discount

	Model	Crash Prevented		Fatalities Eliminated		MAIS 1-5 Injuries		PDOVs	
Year	Year	Low	High	Low	High	Low	High	Low	High
1	2021	0	0	0	0	0	0	0	0
2	2022	138	188	0	0	95	126	172	232
3	2023	928	1,265	2	3	638	846	1,148	1,558
4	2024	4,193	5,728	10	13	2,887	3,832	5,187	7,047
5	2025	10,349	14,168	24	32	7,131	9,490	12,787	17,407
6	2026	23,536	32,309	54	73	16,234	21,676	29,043	39,634
7	2027	44,605	61,392	102	138	30,794	41,249	54,976	75,201
8	2028	64,357	88,762	146	200	44,461	59,711	79,239	108,599
9	2029	77,911	107,636	177	242	53,856	72,478	95,850	131,566
10	2030	90,013	124,531	204	279	62,252	83,923	110,663	152,096
11	2031	100,723	139,525	228	313	69,689	94,095	123,755	170,287
12	2032	110,194	152,818	249	342	76,272	103,126	135,317	186,391
13	2033	118,581	164,620	268	368	82,106	111,157	145,542	200,668
14	2034	126,392	175,632	286	393	87,543	118,658	155,055	213,976
15	2035	133,173	185,222	301	414	92,268	125,201	163,302	225,544
16	2036	139,022	193,520	314	432	96,349	130,873	170,405	235,538
17	2037	144,196	200,879	325	448	99,962	135,910	176,679	244,386
18	2038	148,502	207,029	335	461	102,972	140,128	181,890	251,764
19	2039	152,185	212,307	343	473	105,551	143,756	186,340	258,085
20	2040	155,891	217,610	351	484	108,145	147,398	190,820	264,441
21	2041	159,954	223,404	360	497	110,984	151,369	195,741	271,398
22	2042	151,452	211,629	341	471	105,102	143,429	185,294	257,025
23	2043	152,442	213,096	343	474	105,803	144,456	186,468	258,749
24	2044	153,177	214,195	345	476	106,326	145,227	187,338	260,036
25	2045	153,840	215,177	346	478	106,795	145,915	188,123	261,190
26	2046	154,529	216,188	347	480	107,282	146,618	188,947	262,385
27	2047	155,123	217,055	349	482	107,700	147,220	189,658	263,413
28	2048	155,588	217,736	350	484	108,028	147,693	190,212	264,218
29	2049	156,208	218,630	351	486	108,463	148,310	190,960	265,285
30	2050	156,787	219,463	352	487	108,869	148,884	191,657	266,280

Table V-28
MY Benefits for **LTVs**
Free-Rider Approach
@3 Percent Discount

	Model	Crash Prevented		Fatalities Eliminated		MAIS 1-5 Injuries		PDOVs	
Year	Year	Low	High	Low	High	Low	High	Low	High
1	2021	0	0	0	0	0	0	0	0
2	2022	133	181	0	0	91	121	165	223
3	2023	894	1,219	2	3	615	815	1,106	1,501
4	2024	3,944	5,388	9	12	2,716	3,604	4,879	6,628
5	2025	9,745	13,342	22	30	6,715	8,937	12,041	16,392
6	2026	22,231	30,519	51	69	15,334	20,475	27,433	37,438
7	2027	42,168	58,036	96	131	29,111	38,994	51,973	71,091
8	2028	60,927	84,028	138	189	42,091	56,525	75,017	102,809
9	2029	73,890	102,077	168	229	51,076	68,733	90,905	124,774
10	2030	85,672	118,522	194	266	59,249	79,871	105,328	144,759
11	2031	96,100	133,116	218	298	66,489	89,771	118,075	162,468
12	2032	105,263	145,975	238	327	72,858	98,507	129,264	178,048
13	2033	113,247	157,211	256	352	78,412	106,152	138,997	191,640
14	2034	120,650	167,650	273	375	83,565	113,264	148,013	204,253
15	2035	127,176	176,879	287	395	88,113	119,561	155,950	215,387
16	2036	132,885	184,975	300	413	92,095	125,093	162,884	225,139
17	2037	137,916	192,129	311	429	95,608	129,990	168,985	233,743
18	2038	141,956	197,901	320	441	98,433	133,950	173,873	240,666
19	2039	145,718	203,284	328	453	101,066	137,646	178,421	247,117
20	2040	149,196	208,264	336	464	103,500	141,067	182,625	253,084
21	2041	152,849	213,480	344	475	106,054	144,645	187,047	259,343
22	2042	154,152	215,402	347	479	106,976	145,986	188,597	261,607
23	2043	155,985	218,050	351	485	108,262	147,814	190,801	264,764
24	2044	157,772	220,620	355	490	109,515	149,584	192,956	267,835
25	2045	159,485	223,076	359	496	110,715	151,272	195,026	270,776
26	2046	160,913	225,121	362	500	111,714	152,677	196,752	273,226
27	2047	162,487	227,362	365	505	112,814	154,212	198,660	275,919
28	2048	164,077	229,618	369	510	113,923	155,754	200,590	278,635
29	2049	165,408	231,508	372	514	114,852	157,046	202,206	280,910
30	2050	166,939	233,675	375	519	115,919	158,526	204,067	283,523

Table V-29
MY Benefits for **PCs**
Free-Rider Approach
@7 Percent Discount

	Model	Crash Prevented		Fatalities Eliminated		MAIS 1-5 Injuries		PDOVs	
Year	Year	Low	High	Low	High	Low	High	Low	High
1	2021	0	0	0	0	0	0	0	0
2	2022	129	175	0	0	89	117	160	216
3	2023	865	1,180	2	3	596	788	1,072	1,453
4	2024	3,858	5,267	9	12	2,656	3,523	4,773	6,481
5	2025	9,421	12,892	22	29	6,491	8,633	11,644	15,843
6	2026	21,181	29,062	48	66	14,607	19,492	26,144	35,661
7	2027	39,671	54,573	90	123	27,382	36,657	48,906	66,867
8	2028	56,772	78,264	129	176	39,215	52,635	69,916	95,780
9	2029	68,431	94,499	155	212	47,296	63,616	84,205	115,536
10	2030	78,891	109,100	179	245	54,552	73,507	97,008	133,280
11	2031	88,226	122,168	200	274	61,034	82,373	108,419	149,135
12	2032	96,396	133,637	218	299	66,713	90,165	118,393	163,028
13	2033	103,751	143,986	235	322	71,830	97,207	127,360	175,548
14	2034	110,627	153,680	250	344	76,616	103,810	135,734	187,262
15	2035	116,575	162,093	263	362	80,761	109,550	142,968	197,410
16	2036	121,749	169,434	275	378	84,371	114,568	149,250	206,250
17	2037	126,349	175,978	285	393	87,583	119,047	154,829	214,119
18	2038	130,065	181,290	293	404	90,182	122,693	159,324	220,489
19	2039	133,370	186,026	301	414	92,496	125,948	163,317	226,160
20	2040	136,645	190,715	308	425	94,788	129,169	167,274	231,777
21	2041	140,147	195,715	316	436	97,237	132,598	171,514	237,778
22	2042	132,766	185,498	299	413	92,131	125,711	162,440	225,302
23	2043	133,681	186,855	301	416	92,780	126,661	163,527	226,898
24	2044	134,272	187,745	302	417	93,201	127,289	164,222	227,935
25	2045	134,963	188,764	304	420	93,689	128,000	165,045	229,135
26	2046	135,512	189,573	305	421	94,078	128,565	165,698	230,090
27	2047	136,089	190,414	306	423	94,484	129,147	166,389	231,087
28	2048	136,445	190,940	307	424	94,736	129,514	166,812	231,706
29	2049	136,926	191,637	308	426	95,074	129,997	167,391	232,536
30	2050	137,462	192,408	309	427	95,450	130,527	168,037	233,457

Table V-30
MY Benefits for **LTVs**
Free-Rider Approach
@7 Percent Discount

	Model	Crash Prevented		Fatalities Eliminated		MAIS 1-5 Injuries		PDOVs	
Year	Year	Low	High	Low	High	Low	High	Low	High
1	2021	0	0	0	0	0	0	0	0
2	2022	127	172	0	0	87	115	157	213
3	2023	838	1,142	2	3	577	763	1,037	1,407
4	2024	3,659	4,997	8	11	2,519	3,342	4,527	6,148
5	2025	8,900	12,179	20	28	6,132	8,156	10,999	14,967
6	2026	19,976	27,408	46	62	13,776	18,382	24,657	33,632
7	2027	37,478	51,554	85	116	25,869	34,628	46,204	63,170
8	2028	53,753	74,098	122	167	37,129	49,831	66,200	90,684
9	2029	64,968	89,712	148	202	44,902	60,392	79,945	109,687
10	2030	75,144	103,915	170	233	51,961	70,012	92,403	126,948
11	2031	84,171	116,548	191	261	58,228	78,581	103,438	142,277
12	2032	92,148	127,742	209	286	63,772	86,185	113,177	155,840
13	2033	99,169	137,623	224	308	68,657	92,909	121,737	167,793
14	2034	105,631	146,735	239	328	73,155	99,117	129,606	178,803
15	2035	111,336	154,805	252	346	77,131	104,623	136,545	188,537
16	2036	116,319	161,874	263	361	80,607	109,454	142,596	197,050
17	2037	120,771	168,205	272	375	83,716	113,788	147,995	204,664
18	2038	124,358	173,332	280	386	86,225	117,306	152,335	210,813
19	2039	127,586	177,955	288	396	88,484	120,483	156,234	216,350
20	2040	130,602	182,280	294	406	90,596	123,456	159,878	221,528
21	2041	133,695	186,703	301	416	92,760	126,492	163,619	226,830
22	2042	134,788	188,322	303	419	93,534	127,624	164,915	228,733
23	2043	136,373	190,617	307	424	94,648	129,211	166,820	231,466
24	2044	137,906	192,826	310	429	95,723	130,734	168,666	234,103
25	2045	139,325	194,866	313	433	96,718	132,138	170,379	236,542
26	2046	140,566	196,645	316	437	97,587	133,361	171,878	238,672
27	2047	141,985	198,665	319	441	98,577	134,744	173,597	241,099
28	2048	143,327	200,571	322	446	99,514	136,048	175,226	243,393
29	2049	144,453	202,172	325	449	100,300	137,143	176,592	245,319
30	2050	145,730	203,980	328	453	101,190	138,378	178,143	247,498

Table V-31
MY Benefits for **PCs**
No Free-Rider Approach
@3 Percent Discount

	Model	Crash Prevented		Fatalities Eliminated		MAIS 1-5 Injuries		PDOVs	
Year	Year	Low	High	Low	High	Low	High	Low	High
1	2021	0	0	0	0	0	0	0	0
2	2022	2,008	2,760	5	6	1,386	1,853	2,477	3,384
3	2023	6,164	8,478	14	19	4,255	5,694	7,600	10,389
4	2024	17,155	23,617	39	53	11,844	15,870	21,142	28,925
5	2025	30,068	41,443	68	93	20,768	27,869	37,033	50,724
6	2026	52,390	72,306	119	163	36,202	48,660	64,483	88,431
7	2027	77,310	106,843	175	240	53,447	71,959	95,094	130,571
8	2028	91,027	125,958	206	283	62,957	84,893	111,899	153,822
9	2029	95,553	132,370	216	297	66,113	89,272	117,399	161,550
10	2030	100,220	138,978	227	311	69,366	93,784	123,071	169,516
11	2031	104,402	144,917	236	324	72,285	97,846	128,147	176,664
12	2032	108,191	150,311	245	336	74,932	101,540	132,740	183,147
13	2033	111,637	155,229	252	347	77,340	104,912	136,911	189,049
14	2034	115,065	160,122	260	357	79,737	108,268	141,060	194,922
15	2035	118,014	164,349	266	367	81,802	111,173	144,623	199,983
16	2036	120,521	167,958	272	374	83,560	113,659	147,645	204,294
17	2037	122,769	171,201	277	382	85,137	115,896	150,351	208,163
18	2038	124,665	173,950	281	387	86,470	117,797	152,629	211,434
19	2039	126,183	176,164	284	392	87,539	119,334	154,445	214,059
20	2040	127,919	178,677	288	398	88,759	121,070	156,531	217,051
21	2041	129,904	181,529	292	404	90,150	123,033	158,926	220,462
22	2042	122,240	170,885	275	380	84,843	115,844	149,522	207,490
23	2043	122,798	171,719	276	382	85,239	116,430	150,181	208,466
24	2044	123,134	172,235	277	383	85,481	116,797	150,573	209,061
25	2045	123,617	172,947	278	384	85,822	117,294	151,147	209,900
26	2046	124,138	173,706	279	386	86,189	117,821	151,771	210,801
27	2047	124,507	174,248	280	387	86,450	118,197	152,212	211,441
28	2048	124,765	174,629	280	388	86,632	118,464	152,518	211,890
29	2049	125,144	175,178	281	389	86,898	118,843	152,974	212,543
30	2050	125,571	175,792	282	390	87,198	119,266	153,489	213,277

Table V-32
MY Benefits for **LTVs**
No Free-Rider Approach
@3 Percent Discount

	Model	Crash Prevented		Fatalities Eliminated		MAIS 1-5 Injuries		PDOVs	
Year	Year	Low	High	Low	High	Low	High	Low	High
1	2021	0	0	0	0	0	0	0	0
2	2022	1,998	2,746	5	6	1,379	1,844	2,463	3,366
3	2023	6,132	8,439	14	19	4,233	5,670	7,559	10,338
4	2024	17,006	23,424	39	53	11,743	15,746	20,952	28,680
5	2025	29,745	41,017	68	92	20,548	27,590	36,626	50,189
6	2026	51,827	71,557	118	161	35,818	48,167	63,779	87,496
7	2027	76,366	105,572	173	237	52,800	71,115	93,920	128,995
8	2028	89,890	124,418	204	279	62,176	83,868	110,487	151,918
9	2029	94,478	130,912	214	293	65,375	88,301	116,066	159,749
10	2030	99,169	137,548	224	308	68,644	92,830	121,769	167,753
11	2031	103,406	143,559	234	321	71,600	96,938	126,914	174,992
12	2032	107,200	148,956	242	333	74,249	100,633	131,514	181,481
13	2033	110,461	153,615	249	343	76,529	103,829	135,460	187,069
14	2034	113,786	158,363	257	353	78,854	107,085	139,485	192,767
15	2035	116,699	162,534	263	363	80,893	109,952	143,004	197,763
16	2036	119,275	166,236	269	371	82,698	112,500	146,112	202,190
17	2037	121,675	169,689	274	378	84,381	114,878	149,005	206,315
18	2038	123,485	172,315	278	384	85,653	116,695	151,178	209,438
19	2039	125,310	174,957	282	389	86,936	118,521	153,372	212,585
20	2040	127,039	177,458	286	395	88,150	120,248	155,451	215,564
21	2041	129,069	180,371	290	401	89,572	122,251	157,902	219,049
22	2042	129,233	180,667	291	402	89,698	122,478	158,074	219,364
23	2043	130,000	181,796	292	404	90,239	123,265	158,986	220,695
24	2044	131,004	183,247	295	407	90,944	124,267	160,194	222,425
25	2045	131,793	184,390	296	410	91,499	125,056	161,142	223,785
26	2046	132,468	185,366	298	412	91,973	125,731	161,954	224,948
27	2047	133,337	186,608	300	415	92,581	126,583	163,005	226,437
28	2048	134,111	187,713	301	417	93,122	127,341	163,942	227,763
29	2049	134,785	188,676	303	419	93,593	128,001	164,759	228,919
30	2050	135,670	189,931	305	422	94,211	128,859	165,833	230,430

Table V-33
MY Benefits for **PCs**
No Free-Rider Approach
@7 Percent Discount

	Model	Crash Prevented		Fatalities Eliminated		MAIS 1-5 Injuries		PDOVs	
Year	Year	Low	High	Low	High	Low	High	Low	High
1	2021	0	0	0	0	0	0	0	0
2	2022	1,521	2,087	3	5	1,049	1,400	1,877	2,561
3	2023	4,753	6,529	11	15	3,279	4,382	5,864	8,006
4	2024	13,416	18,446	31	42	9,259	12,387	16,543	22,608
5	2025	23,710	32,642	54	74	16,370	21,936	29,218	39,977
6	2026	41,530	57,257	94	129	28,687	38,509	51,143	70,068
7	2027	61,698	85,188	140	191	42,640	57,343	75,925	104,162
8	2028	72,894	100,781	165	226	50,401	67,892	89,646	123,135
9	2029	76,882	106,424	174	239	53,181	71,742	94,495	129,940
10	2030	80,896	112,103	183	251	55,978	75,618	99,375	136,789
11	2031	84,628	117,395	192	263	58,581	79,234	103,908	143,164
12	2032	87,887	122,031	199	273	60,857	82,408	107,860	148,739
13	2033	90,959	126,410	206	283	63,004	85,408	111,582	153,998
14	2034	93,959	130,688	212	292	65,100	88,341	115,214	159,134
15	2035	96,554	134,404	218	300	66,917	90,894	118,351	163,586
16	2036	98,786	137,613	223	307	68,481	93,103	121,042	167,421
17	2037	100,774	140,479	227	313	69,876	95,079	123,436	170,842
18	2038	102,472	142,938	231	318	71,069	96,779	125,477	173,770
19	2039	103,766	144,829	234	322	71,981	98,092	127,025	176,010
20	2040	105,275	147,013	237	327	73,041	99,602	128,837	178,611
21	2041	106,926	149,390	241	332	74,199	101,239	130,827	181,449
22	2042	100,616	140,633	226	313	69,830	95,327	123,082	170,773
23	2043	101,057	141,297	227	314	70,144	95,796	123,600	171,547
24	2044	101,409	141,831	228	315	70,396	96,174	124,013	172,167
25	2045	101,886	142,532	229	317	70,733	96,661	124,583	172,995
26	2046	102,207	143,008	230	318	70,961	96,994	124,964	173,554
27	2047	102,623	143,612	231	319	71,253	97,412	125,463	174,272
28	2048	102,790	143,863	231	320	71,372	97,590	125,659	174,565
29	2049	103,173	144,414	232	321	71,640	97,970	126,120	175,223
30	2050	103,440	144,803	232	322	71,829	98,239	126,441	175,685

Table V-34
Lifetime Benefits for MY **LTVs**
No Free-Rider Approach
@7 Percent Discount

	Model	Crash Prevented		Fatalities Eliminated		MAIS 1-5 Injuries		PDOVs	
Year	Year	Low	High	Low	High	Low	High	Low	High
1	2021	0	0	0	0	0	0	0	0
2	2022	1,506	2,067	3	5	1,039	1,387	1,858	2,536
3	2023	4,670	6,417	11	14	3,222	4,308	5,760	7,868
4	2024	13,140	18,074	30	41	9,069	12,140	16,199	22,147
5	2025	23,146	31,876	53	72	15,982	21,425	28,519	39,032
6	2026	40,589	55,975	92	126	28,040	37,652	49,979	68,489
7	2027	60,242	83,193	137	187	41,636	56,006	74,126	101,711
8	2028	71,210	98,468	162	221	49,239	66,339	87,567	120,298
9	2029	75,186	104,091	170	233	52,010	70,175	92,404	127,082
10	2030	79,300	109,903	180	246	54,876	74,140	97,408	134,097
11	2031	82,993	115,138	188	258	57,452	77,716	101,896	140,404
12	2032	86,297	119,834	195	268	59,758	80,928	105,904	146,053
13	2033	89,169	123,930	201	277	61,765	83,737	109,381	150,971
14	2034	92,090	128,097	208	286	63,807	86,593	112,919	155,974
15	2035	94,665	131,782	214	294	65,609	89,124	116,031	160,389
16	2036	96,894	134,984	219	301	67,170	91,327	118,721	164,218
17	2037	99,033	138,059	223	308	68,670	93,444	121,301	167,895
18	2038	100,503	140,197	226	312	69,704	94,925	123,063	170,434
19	2039	102,122	142,539	230	317	70,841	96,544	125,009	173,224
20	2040	103,571	144,638	233	322	71,860	97,995	126,750	175,722
21	2041	105,262	147,070	237	327	73,045	99,669	128,790	178,629
22	2042	105,382	147,297	237	328	73,139	99,846	128,911	178,864
23	2043	106,118	148,377	239	330	73,658	100,597	129,789	180,141
24	2044	106,842	149,431	240	332	74,168	101,328	130,656	181,391
25	2045	107,535	150,436	242	334	74,655	102,022	131,489	182,587
26	2046	108,073	151,216	243	336	75,033	102,562	132,134	183,515
27	2047	108,805	152,264	245	338	75,546	103,282	133,020	184,771
28	2048	109,468	153,210	246	340	76,009	103,931	133,822	185,906
29	2049	110,051	154,044	247	342	76,417	104,503	134,528	186,906
30	2050	110,776	155,072	249	344	76,922	105,206	135,407	188,144

Summary of MY Benefits

For simplicity, the analysis consolidated the benefit estimates from both the “free-rider” and “no free-rider’ approaches. These two approaches deployed a different treatment on the distribution of benefits from crashes involving different MY vehicles. Combining results from these two approaches results a wider range of MY benefits than the range of benefits for the individual approach. The lower bound of the range represents the low benefit estimates from the “free-rider" approach and the upper bound of the range represents the high benefit estimates based on the "no free-rider" approach. The low and high benefit estimates for each approach correspond to the low and high app effectiveness, respectively. Tables V-35 and V-36 summarize the MY benefits of the proposed rule at a 3 percent and 7 percent discount, respectively.

Table V-35
MY Benefits for Light Vehicles
@3 Percent Discount

	Model	Crash Prevented		Fatalities Eliminated		MAIS 1-5 Injuries		PDOVs	
Year	Year	Low	High	Low	High	Low	High	Low	High
1	2021	0	0	0	0	0	0	0	0
2	2022	271	5,506	1	12	187	3,697	336	6,750
3	2023	1,821	16,917	4	38	1,254	11,363	2,255	20,727
4	2024	8,138	47,041	19	106	5,604	31,616	10,066	57,606
5	2025	20,094	82,461	46	186	13,847	55,459	24,828	100,913
6	2026	45,766	143,863	104	323	31,567	96,827	56,477	175,926
7	2027	86,774	212,415	198	477	59,905	143,074	106,948	259,566
8	2028	125,283	250,375	285	562	86,552	168,761	154,257	305,740
9	2029	151,801	263,281	345	590	104,932	177,573	186,755	321,299
10	2030	175,685	276,526	398	619	121,501	186,614	215,991	337,269
11	2031	196,823	288,476	446	645	136,178	194,784	241,830	351,656
12	2032	215,391	299,268	487	669	149,129	202,173	264,254	364,628
13	2033	222,098	321,830	502	720	153,870	217,309	272,371	392,308
14	2034	228,851	343,282	517	767	158,591	231,922	280,546	418,229
15	2035	234,712	362,101	530	809	162,695	244,762	287,627	440,931
16	2036	239,796	378,496	541	845	166,258	255,966	293,758	460,676
17	2037	244,444	393,009	551	877	169,518	265,900	299,356	478,129
18	2038	248,150	404,930	559	903	172,124	274,078	303,807	492,430
19	2039	251,493	415,591	566	926	174,475	281,402	307,817	505,202
20	2040	254,958	425,875	574	948	176,909	288,466	311,982	517,525
21	2041	258,973	436,885	583	972	179,722	296,015	316,828	530,741
22	2042	251,474	427,030	566	950	174,540	289,414	307,596	518,632
23	2043	252,797	431,146	569	959	175,478	292,270	309,167	523,513
24	2044	254,138	434,815	572	967	176,425	294,812	310,767	527,871
25	2045	255,409	438,253	574	974	177,320	297,187	312,289	531,965
26	2046	256,606	441,309	577	981	178,162	299,295	313,725	535,611
27	2047	257,844	444,417	580	987	179,030	301,432	315,217	539,332
28	2048	258,876	447,353	582	994	179,754	303,447	316,460	542,853
29	2049	259,929	450,138	584	1,000	180,492	305,356	317,732	546,196
30	2050	261,241	453,138	587	1,006	181,408	307,409	319,322	549,803

Table V-36
MY Benefits for Light Vehicles
@7 Percent Discount

Year	Model Year	Crash Prevented		Fatalities Eliminated		MAIS 1-5 Injuries		PDOVs	
		Low	High	Low	High	Low	High	Low	High
1	2021	0	0	0	0	0	0	0	0
2	2022	256	4,154	1	9	176	2,787	317	5,096
3	2023	1,703	12,946	4	29	1,172	8,689	2,109	15,874
4	2024	7,517	36,520	17	82	5,175	24,527	9,300	44,755
5	2025	18,321	64,517	42	145	12,623	43,361	22,643	79,010
6	2026	41,157	113,231	94	255	28,383	76,161	50,801	138,557
7	2027	77,149	168,381	176	378	53,251	113,350	95,110	205,873
8	2028	110,525	199,249	251	447	76,343	134,231	136,116	243,433
9	2029	133,399	210,514	303	472	92,198	141,918	164,150	257,022
10	2030	154,035	222,006	349	497	106,513	149,758	189,411	270,886
11	2031	167,621	238,716	379	535	116,033	160,954	205,804	291,412
12	2032	174,185	261,378	394	585	120,615	176,350	213,764	318,868
13	2033	180,128	281,609	407	630	124,769	190,116	220,962	343,341
14	2034	186,049	300,416	420	672	128,907	202,927	228,133	366,065
15	2035	191,219	316,898	432	708	132,525	214,173	234,382	385,947
16	2036	195,680	331,308	441	740	135,651	224,022	239,763	403,300
17	2037	199,807	344,183	450	768	138,545	232,835	244,737	418,783
18	2038	202,975	354,622	457	791	140,773	239,999	248,540	431,301
19	2039	205,888	363,981	464	811	142,823	246,431	252,034	442,510
20	2040	208,845	372,995	470	831	144,901	252,625	255,587	453,305
21	2041	212,188	382,418	478	851	147,244	259,091	259,617	464,608
22	2042	205,999	373,820	464	832	142,969	253,336	251,993	454,035
23	2043	207,175	377,472	466	839	143,803	255,872	253,389	458,363
24	2044	208,251	380,572	468	846	144,564	258,023	254,669	462,038
25	2045	209,421	383,630	471	853	145,388	260,137	256,071	465,677
26	2046	210,280	386,219	473	858	145,994	261,926	257,098	468,762
27	2047	211,429	389,079	475	864	146,799	263,891	258,483	472,186
28	2048	212,258	391,511	477	870	147,381	265,562	259,481	475,099
29	2049	213,224	393,809	479	875	148,057	267,140	260,648	477,855
30	2050	214,216	396,388	481	880	148,751	268,906	261,848	480,956

Figure V-12 depicts the MY crash benefits at a 3 percent discount rate. This is used as an example to show the benefit patterns over 30 MY vehicles. The two curves represent the low and high bounds of the benefit estimates, respectively. MY benefits for fatalities, MAIS 1-5 injuries, and PDOVs follow the same patterns. The MY benefits at a 7 percent discount rate also follow the same pattern. As shown, the decrease benefits between MY 2041 and MY 2043 is due to the vehicle sales projection. The agency projected a slight decrease in sales for these MY vehicles.

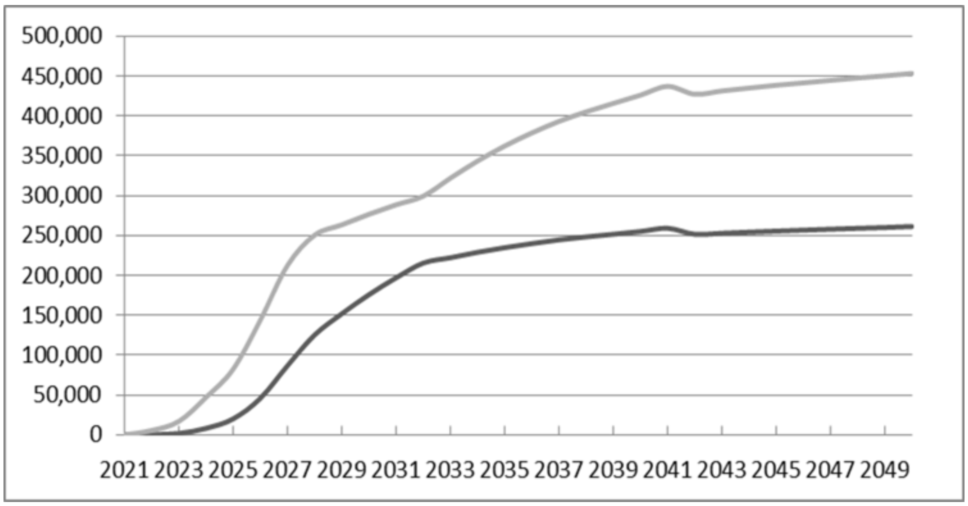


Figure V-12
Range of MY Benefits by Model Year - Crashes

G. Non-Quantified Benefits

As discussed above, the agency has only quantified potential benefits of this rule derived from the assumed adoption of IMA and LTA. Although this assumption allows the agency to provide a reasonable quantification of the potential benefits of this rulemaking, it does not account for many other potential benefits of V2V. The non-quantified benefits of the proposed rule can come from several sources: (1) the effects of enhancing vehicle-resident safety systems, (2) the incremental benefits over the current vehicle-resident safety systems, (3) the potential impact of the next generation V2V apps that would actively assist drivers to avoid crashes rather than simply issuing warnings, (4) the impact of enabling wide range deployment of V2P and V2I apps, and (5) the effects of paving the way for automation. The agency does not quantify the potential impacts of these sources primarily due to lack of data (e.g., effectiveness of the apps, incremental effective rate of the V2V apps over the vehicle-resident systems, etc.) that can be used to discern these benefits.

The Effect for Enhancing Vehicle-Resident Safety Systems

For vehicles equipped with current on-board sensors, DSRC-based V2V can offer a fundamentally different, but complementary, source of information that can significantly enhance the reliability and accuracy of the information available. Instead of relying on each vehicle to sense its surroundings on its own, V2V enables surrounding vehicles to help each other by reporting safety information to each other. V2V communication can also detect threat vehicles that are not in the sensors' field of view, and can use a DSRC signal to validate a return from a vehicle-based sensor. As Hyundai Motor Group offered, "…no other current technology, other than DSRC, has been tested and proven to show the properties of low-latency and 360-degree 'view' capability in a safety event." This added capability can potentially lead to improved warning timing and a reduction in the number of false warnings, thereby adding confidence to the overall safety system, and increasing consumer satisfaction and acceptance. The vehicle-resident FCW, BSW/LCW systems can be improved by BSMs. However, the agency could not quantify the benefit due to lack of the measurement of how BSM can improve the vehicle-resident systems.

Incremental Benefits of the V2V Apps

Due to the sensing advantage of the V2V apps, the agency believes that these apps also have some incremental benefits over the vehicle-resident version of the systems. For example, V2V-based FCW and LCM might perform better than the vehicle-resident systems. However, benefits from these apps could accrue if they add a marginal effectiveness to the existing in-vehicle systems, or if they enable the installation of these apps in vehicles that do not voluntarily have these systems. This later effect would occur due to the significant marginal cost reduction for these apps that would result from V2V. However, we do not have sufficient data to determine the marginal effectiveness of V2V for these apps and the added installation rates. Therefore, we did not quantify this type of benefits.

Potential Impact of Next Generation V2V Apps

The agency believes that the V2V apps will be evolved as did the vehicle-resident systems. The next generation V2V apps, we envision, can also actively assist drivers to avoid crashes as did the vehicle-resident crash avoidance systems (such as advance brake assist). Furthermore, the new apps might be applicable to motorcycle crashes. V2V could increase the adoption of these apps to lower incremental cost.

The Impact of Enabling V2P and V2I Apps

The V2V also is the foundation for the deployment V2P and V2I apps. For V2P, pedestrians can carry devices (such as mobile phones) with a DSRC chip that can send out a safety signal to DSRC devices in the vehicles and vice versa. Both the driver and the pedestrian could be warned if a possible conflict arises. Specifically, V2P can protect pedestrians in crosswalk and improve mobility. However, there are many issues to be resolved concerning V2P apps. The agency is developing a research plan that will investigate issues relating to V2P communication, safety applications, and human factors, and among other things.

For V2I, the same wireless technology that supports V2V apps (5.9 GHz DSRC) will also enable a broader set of safety and mobility applications when combined with compatible roadway infrastructure. The potential V2I apps have been identified included: Red Light Violation Warning, Curve Speed Warning, Stop Sign Gap Assist, Reduced Speed Zone Warning, Spot Weather Information Warning, Stop Sign Violation Warning, Railroad Crossing Violation Warning, and Oversize Vehicle Warning.[108] These V2I apps can mitigate congestion and facilitate green transportation choices, thus reducing the energy consumptions and environmental impacts. Please consult the DOT sponsored contractor report for some estimated benefits for these V2I applications.[109]

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[108] The Connected Vehicle Core System Architecture, See www.its.dot.gov/research/systems_engineering.htm (last accessed Jan. 9, 2014).

[109] Estimated Benefits of Connected Vehicle Applications: Dynamic Mobility Applications, AERIS, V2I Safety, and Road Weather Management (by Noblis), August 20, 2015, FHWA-JPO-15-255

The Effects of Paving the Way for Automation

The fusion of V2V and vehicle-resident technologies will be beneficial to the further development of vehicle automation systems, including the potential for truly self-driving vehicles. V2V would accomplish this by connecting vehicles not only with other vehicles, but also with roadway infrastructure (V2I), and even with pedestrians (V2P). These technologies (collectively referred to as "V2X technology") can augment sensors to enhance both range and resolution and provide more data for safety systems. Ultimately V2X technology would provide a vehicle with the highest level of awareness of its surroundings and allow the automation systems to react far quicker to situations than they would with sensors. Therefore, V2V is important to full automation by allowing vehicles to monitor roadway, traffic, and driving conditions and timely perform safety-critical functions.

CHAPTER VI. MONETIZED BENEFITS

Monetized benefits were derived by applying the comprehensive cost for a fatality to the total equivalent lives saved (i.e., fatal equivalents). To calculate fatal equivalents, nonfatal MAIS injuries and PDOVs must be expressed in terms of fatalities. This is done by comparing the comprehensive cost of preventing nonfatal injuries to that of preventing a fatality. Comprehensive costs included economic costs and the value of quality life (QALYs - quality adjusted life years). Economic costs reflect the tangible costs of reducing fatalities and injuries include savings from medical care, emergency services, insurance administration, workplace costs, legal costs, congestion and property damage, as well as lost productivity. The QALY captures the intangible value of lost quality-of-life that results from these fatalities and injuries. The unit costs for these components are expressed on a per-person basis for all MAIS injury levels and per PDOV for PDOVs. Table VI-1 shows the comprehensive values and the relative fatality ratios for MAIS injuries and PDOVs that were used to derived the fatal equivalents.[110] As shown, the comprehensive cost of preventing a fatality is valued at $9.7 million. A MAIS 5 injury, for example, is 0.6136 fatal equivalents (derived by dividing the comprehensive cost of a MAIS 5 injury into the comprehensive cost of a fatality). Thus, monetized benefits can be derived by multiplying $9.7 million by the derived fatal equivalents.

Table VI-1 also shows the unit costs for congestion and property damage. Congestion costs included travel delay, added fuel usage, and adverse environmental impacts cost. These two costs are part of the comprehensive cost. Separating these two costs is because these costs will be used later to calculate the net costs of the proposed rule. The net costs are defined as the total vehicle costs minus the savings from reducing property damage and crash related congestion.

[110] Revised to 2014 $ from the unit costs published in this report, Blincoe, L. J., Miller, T. R., Zaloshnja, E., & Lawrence, B. A. (2015, May). The economic and societal impact of motor vehicle crashes, 2010. (Revised) (Report No. DOT HS 812 013). Washington, DC: National Highway Traffic Safety Administration

Table VI-1
Unit Congestion, Property Damage, and Comprehensive Cost
(2014 $)

Injury Category	Congestion	Property Damage	Comprehensive Cost	Relative Fatality Ratio
PDOVs	$2,280	$3,908	$6,591	0.0007
MAIS 0	$1,535	$2,923	$4,753	0.0005
MAIS 1	$1,545	$8,641	$47,144	0.0049
MAIS 2	$1,572	$9,239	$449,239	0.0463
MAIS 3	$1,615	$17,400	$1,065,032	0.1097
MAIS 4	$1,638	$17,727	$2,612,382	0.2690
MAIS 5	$1,657	$16,385	$5,958,375	0.6136
Fatality	$6,200	$12,172	$9,710,659	1.0000

In parallel to the benefit discussion in the Benefits chapter, the maximum monetized annual benefits of the proposed rule are presented first followed by the annual monetized benefits from 2021 to 2060 and then the monetized lifetime MY benefits.

A. Monetized Maximum Annual Benefits

Based on the process discussed above to translate the maximum annual benefits into fatal equivalents and monetized value, the proposed rule would save 5,634 to 7,617 fatal equivalents and $54.7 to $74.0 billion annually when all on-road light vehicles have the DSRC radios and the apps IMA and LTA. Of the monetized savings, $7.7 to $10.6 billion are from reducing crash related congestion and property damaged vehicles. Of these, $2.1 to $2.9 billion are from congestion savings and $5.6 to $7.7 billion are from property damaged vehicles. Table VI-2 presents these statistics.

Table VI-2
Maximum Annual Monetized Benefits of the Proposed Rule
(**Undiscounted**, 2014 $ in Millions)

Fatal Equivalents		Total Monetized Benefits		Property Damage and Congestion	
Low	High	Low	High	Low	High
5,634	7,617	$54,709.32	$73,967.78	$7,677.96	$10,634.52

Separately by apps, IMA would save 4,245 to 5,252 fatal equivalents and $41.2 to $51.0 billion annually. Of the monetized savings, $5.8 to $7.4 billion are from reducing crash related congestion and property damaged vehicles. LTA would save 1,389 to 2,366 fatal equivalents and $13.5 to $23.0 billion annually. Of the monetized values, $1.9 to $3.2 billion are savings from reducing crash related congestion and property damaged only vehicles. Table VI-3 presents these statistics by apps.

Table VI-3
Maximum Annual Monetized Benefits of the Proposed Rule by Apps
(**Undiscounted**, 2014 $ in Millions)

IMA

Fatal Equivalents		Total Monetized Benefits		Property Damage and Congestion	
Low	High	Low	High	Low	High
4,245	5,252	$41,217.54	$50,997.18	$5,769.26	$7,384.58

LTA

1,389	2,366	$13,491.79	$22,970.60	$1,908.70	$3,249.94

B. Monetized Annual Benefits

Monetized Annual Benefits of the Proposed Rule

Tables VI-4 shows the undiscounted annual fatal equivalents, monetized benefits, and property damage and congestion savings of the proposed rule from 2021 to 2060. As shown in Table VI-4, in Year 5, the proposed rule would save 129 to 169 fatal equivalents and a total of $1.3 to $1.6 billion annually. About 12 percent of these monetized savings ($176 to $237 million) were from reducing property damage and congestion. In 2060, when all vehicles have the DSRC radios and almost all vehicles have the two safety apps, the proposed rule would save approximately 5,631 to 7,613 fatal equivalents annually. The total associated monetized annual savings would range from $54.7 to $73.9 billion. Of these savings, $7.7 to $10.6 billion would be property damage and congestion savings.

Table VI-4
Annual Monetized Benefits of the Proposed Rule
(**Undiscounted**, 2014 $ in Millions)

Year	Calendar Year	Fatal Equivalents		Total Monetized Benefits		Property Damage and Congestion	
		Low	High	Low	High	Low	High
1	2021	0.00	0.00	$0.00	$0.00	$0.00	$0.00
2	2022	1.98	2.57	$19.18	$24.99	$2.69	$3.60
3	2023	12.98	16.97	$126.05	$164.75	$17.67	$23.75
4	2024	50.94	66.58	$494.62	$646.51	$69.35	$93.20
5	2025	129.38	169.32	$1,256.34	$1,644.21	$176.14	$237.00
6	2026	273.40	358.63	$2,654.86	$3,482.52	$372.24	$501.88
7	2027	492.69	648.24	$4,784.30	$6,294.87	$670.88	$906.96
8	2028	760.14	1,003.08	$7,381.47	$9,740.54	$1,035.15	$1,403.08
9	2029	1,055.03	1,395.74	$10,245.07	$13,553.52	$1,436.84	$1,951.93
10	2030	1,373.29	1,820.47	$13,335.53	$17,677.94	$1,870.39	$2,545.51
11	2031	1,708.97	2,269.74	$16,595.21	$22,040.63	$2,327.71	$3,173.24
12	2032	2,055.46	2,734.45	$19,959.89	$26,553.31	$2,799.80	$3,822.44
13	2033	2,406.57	3,206.42	$23,369.32	$31,136.42	$3,278.19	$4,481.66
14	2034	2,756.78	3,678.26	$26,770.14	$35,718.29	$3,755.42	$5,140.59
15	2035	3,099.49	4,141.07	$30,098.04	$40,212.46	$4,222.44	$5,786.78
16	2036	3,427.08	4,584.47	$33,279.20	$44,518.16	$4,668.90	$6,405.77
17	2037	3,734.36	5,001.37	$36,263.04	$48,566.54	$5,087.70	$6,987.66
18	2038	4,016.39	5,384.96	$39,001.73	$52,291.53	$5,472.13	$7,522.96
19	2039	4,267.25	5,727.35	$41,437.81	$55,616.35	$5,814.11	$8,000.63
20	2040	4,486.82	6,028.11	$43,569.99	$58,536.92	$6,113.46	$8,420.10
21	2041	4,674.40	6,286.06	$45,391.52	$61,041.76	$6,369.24	$8,779.76
22	2042	4,829.59	6,500.30	$46,898.45	$63,122.18	$6,580.86	$9,078.39
23	2043	4,958.71	6,679.27	$48,152.35	$64,860.05	$6,756.97	$9,327.77
24	2044	5,065.75	6,827.92	$49,191.70	$66,303.56	$6,902.96	$9,534.88
25	2045	5,153.64	6,950.12	$50,045.25	$67,490.21	$7,022.85	$9,705.13
26	2046	5,228.04	7,053.49	$50,767.72	$68,493.96	$7,124.33	$9,849.14
27	2047	5,293.45	7,144.11	$51,402.88	$69,373.99	$7,213.54	$9,975.43
28	2048	5,351.13	7,223.76	$51,963.02	$70,147.39	$7,292.20	$10,086.44
29	2049	5,402.91	7,295.12	$52,465.83	$70,840.43	$7,362.81	$10,185.94
30	2050	5,448.79	7,358.22	$52,911.30	$71,453.12	$7,425.36	$10,273.91
31	2051	5,486.64	7,410.41	$53,278.83	$71,959.96	$7,476.97	$10,346.67
32	2052	5,519.98	7,456.51	$53,602.60	$72,407.63	$7,522.44	$10,410.92
33	2053	5,547.41	7,494.52	$53,868.95	$72,776.73	$7,559.85	$10,463.88
34	2054	5,570.75	7,526.96	$54,095.66	$73,091.76	$7,591.69	$10,509.08
35	2055	5,590.30	7,554.13	$54,285.50	$73,355.51	$7,618.36	$10,546.93
36	2056	5,606.76	7,577.01	$54,445.28	$73,577.69	$7,640.80	$10,578.80
37	2057	5,618.70	7,593.79	$54,561.30	$73,740.69	$7,657.10	$10,602.17
38	2058	5,625.16	7,603.20	$54,623.95	$73,832.03	$7,665.92	$10,615.22
39	2059	5,629.36	7,609.56	$54,664.73	$73,893.77	$7,671.66	$10,624.03
40	2060	5,631.45	7,612.92	$54,685.04	$73,926.44	$7,674.53	$10,628.67

Monetized Annual Benefits By Apps

Tables VI-5 and VI-6 show the fatal equivalents, monetized benefits, and property damage and congestion savings for IMA and LTA, respectively. Separately, IMA would save 2 equivalent lives and a total of $16.5 to $20.4 million in the second year of implementation, but this would increase dramatically as apps penetrate the on-road fleet. By 2060, IMA would save 4,245 to 5,252 equivalent lives and $41.2 to $51.0 billion in comprehensive costs. In contrast, LTA would save up to 2,361 equivalent lives and a total of $13.5 to $22.9 billion.

Table VI-5
Annual Monetized Benefits for **IMA**
(Undiscounted, 2014 $ in **Millions**)

Year	Calendar	Fatal Equivalents		Total Monetized Benefits		Property Damage and Congestion	
	Year	Low	High	Low	High	Low	High
1	2021	0.00	0.00	$0.0	$0.00	$0.00	$0.00
2	2022	1.70	2.10	$16.5	$20.40	$2.31	$2.95
3	2023	11.04	13.65	$107.2	$132.59	$15.00	$19.20
4	2024	43.30	53.57	$420.4	$520.17	$58.85	$75.32
5	2025	109.51	135.49	$1,063.4	$1,315.73	$148.85	$190.52
6	2026	229.63	284.12	$2,229.9	$2,758.95	$312.12	$399.51
7	2027	409.60	506.79	$3,977.5	$4,921.23	$556.73	$712.61
8	2028	625.65	774.10	$6,075.5	$7,516.99	$850.39	$1,088.49
9	2029	860.80	1,065.04	$8,358.9	$10,342.23	$1,170.01	$1,497.59
10	2030	1,112.50	1,376.46	$10,803.1	$13,366.36	$1,512.12	$1,935.50
11	2031	1,375.24	1,701.54	$13,354.5	$16,523.09	$1,869.24	$2,392.60
12	2032	1,644.35	2,034.50	$15,967.7	$19,756.31	$2,235.01	$2,860.79
13	2033	1,914.72	2,369.03	$18,593.2	$23,004.83	$2,602.51	$3,331.18
14	2034	2,182.13	2,699.89	$21,189.9	$26,217.65	$2,965.98	$3,796.41
15	2035	2,441.48	3,020.76	$23,708.3	$29,333.58	$3,318.48	$4,247.61
16	2036	2,687.24	3,324.83	$26,094.8	$32,286.32	$3,652.52	$4,675.18
17	2037	2,915.59	3,607.37	$28,312.3	$35,029.97	$3,962.91	$5,072.46
18	2038	3,123.15	3,864.18	$30,327.9	$37,523.73	$4,245.02	$5,433.57
19	2039	3,305.25	4,089.48	$32,096.1	$39,711.51	$4,492.52	$5,750.37
20	2040	3,462.29	4,283.79	$33,621.1	$41,598.40	$4,705.99	$6,023.60
21	2041	3,594.30	4,447.12	$34,903.0	$43,184.42	$4,885.41	$6,253.26
22	2042	3,701.69	4,579.98	$35,945.8	$44,474.64	$5,031.37	$6,440.09
23	2043	3,789.55	4,688.69	$36,799.0	$45,530.29	$5,150.80	$6,592.95
24	2044	3,861.71	4,777.97	$37,499.7	$46,397.24	$5,248.87	$6,718.49
25	2045	3,920.71	4,850.97	$38,072.6	$47,106.10	$5,329.07	$6,821.13
26	2046	3,970.79	4,912.94	$38,559.0	$47,707.87	$5,397.14	$6,908.27
27	2047	4,015.36	4,968.08	$38,991.8	$48,243.34	$5,457.72	$6,985.81
28	2048	4,055.26	5,017.45	$39,379.2	$48,722.71	$5,511.95	$7,055.22
29	2049	4,091.34	5,062.09	$39,729.6	$49,156.19	$5,560.99	$7,117.99
30	2050	4,123.60	5,102.00	$40,042.8	$49,543.76	$5,604.84	$7,174.12
31	2051	4,149.91	5,134.56	$40,298.4	$49,859.95	$5,640.61	$7,219.90
32	2052	4,172.84	5,162.92	$40,521.0	$50,135.33	$5,671.76	$7,259.78
33	2053	4,191.51	5,186.03	$40,702.3	$50,359.72	$5,697.15	$7,292.27
34	2054	4,207.22	5,205.46	$40,854.8	$50,548.41	$5,718.49	$7,319.59
35	2055	4,220.37	5,221.74	$40,982.6	$50,706.50	$5,736.38	$7,342.48
36	2056	4,231.41	5,235.39	$41,089.8	$50,839.09	$5,751.38	$7,361.68
37	2057	4,239.05	5,244.85	$41,164.0	$50,930.89	$5,761.76	$7,374.98
38	2058	4,242.45	5,249.05	$41,196.9	$50,971.69	$5,766.38	$7,380.88
39	2059	4,244.14	5,251.15	$41,213.4	$50,992.08	$5,768.68	$7,383.84
40	2060	4,244.57	5,251.67	$41,217.5	$50,997.18	$5,769.26	$7,384.58

Table VI-6
Annual Monetized Benefits for **LTA**
(Undiscounted, 2014 $ in **Millions**)

	Calendar	Fatal Equivalents		Total Monetized Benefits		Property Damage and Congestion	
Year	Year	Low	High	Low	High	Low	High
1	2021	0.00	0.00	$0.00	$0.00	$0.00	$0.00
2	2022	0.28	0.47	$2.70	$4.59	$0.38	$0.65
3	2023	1.95	3.31	$18.89	$32.16	$2.67	$4.55
4	2024	7.64	13.01	$74.21	$126.34	$10.50	$17.87
5	2025	19.87	33.83	$192.93	$328.48	$27.29	$46.48
6	2026	43.77	74.51	$424.99	$723.57	$60.12	$102.37
7	2027	83.09	141.46	$806.81	$1,373.64	$114.14	$194.35
8	2028	134.49	228.98	$1,306.01	$2,223.55	$184.76	$314.59
9	2029	194.24	330.70	$1,886.15	$3,211.29	$266.84	$454.34
10	2030	260.79	444.01	$2,532.41	$4,311.58	$358.26	$610.01
11	2031	333.73	568.19	$3,240.73	$5,517.54	$458.47	$780.64
12	2032	411.12	699.95	$3,992.22	$6,797.00	$564.79	$961.66
13	2033	491.84	837.39	$4,776.09	$8,131.59	$675.68	$1,150.48
14	2034	574.65	978.37	$5,580.20	$9,500.64	$789.44	$1,344.18
15	2035	658.01	1,120.30	$6,389.71	$10,878.88	$903.96	$1,539.17
16	2036	739.84	1,259.63	$7,184.38	$12,231.85	$1,016.38	$1,730.59
17	2037	818.76	1,393.99	$7,950.71	$13,536.58	$1,124.80	$1,915.19
18	2038	893.23	1,520.78	$8,673.87	$14,767.80	$1,227.11	$2,089.39
19	2039	962.01	1,637.88	$9,341.71	$15,904.84	$1,321.59	$2,250.26
20	2040	1,024.53	1,744.32	$9,948.84	$16,938.52	$1,407.48	$2,396.51
21	2041	1,080.10	1,838.94	$10,488.51	$17,857.35	$1,483.83	$2,526.50
22	2042	1,127.90	1,920.32	$10,952.63	$18,647.53	$1,549.48	$2,638.30
23	2043	1,169.16	1,990.57	$11,353.34	$19,329.76	$1,606.17	$2,734.83
24	2044	1,204.04	2,049.95	$11,691.98	$19,906.32	$1,654.08	$2,816.40
25	2045	1,232.94	2,099.15	$11,972.61	$20,384.11	$1,693.78	$2,884.00
26	2046	1,257.25	2,140.55	$12,208.72	$20,786.10	$1,727.18	$2,940.87
27	2047	1,278.09	2,176.03	$12,411.09	$21,130.66	$1,755.82	$2,989.62
28	2048	1,295.87	2,206.31	$12,583.79	$21,424.68	$1,780.25	$3,031.22
29	2049	1,311.57	2,233.04	$12,736.25	$21,684.25	$1,801.81	$3,067.94
30	2050	1,325.19	2,256.22	$12,868.46	$21,909.36	$1,820.52	$3,099.79
31	2051	1,336.72	2,275.85	$12,980.45	$22,100.02	$1,836.36	$3,126.77
32	2052	1,347.14	2,293.59	$13,081.63	$22,272.29	$1,850.68	$3,151.14
33	2053	1,355.90	2,308.50	$13,166.63	$22,417.01	$1,862.70	$3,171.62
34	2054	1,363.54	2,321.51	$13,240.84	$22,543.35	$1,873.20	$3,189.49
35	2055	1,369.93	2,332.39	$13,302.90	$22,649.01	$1,881.98	$3,204.44
36	2056	1,375.35	2,341.61	$13,355.52	$22,738.60	$1,889.42	$3,217.11
37	2057	1,379.65	2,348.95	$13,397.34	$22,809.81	$1,895.34	$3,227.19
38	2058	1,382.71	2,354.15	$13,427.02	$22,860.34	$1,899.54	$3,234.34
39	2059	1,385.21	2,358.41	$13,451.31	$22,901.69	$1,902.98	$3,240.19
40	2060	1,386.88	2,361.25	$13,467.50	$22,929.25	$1,905.27	$3,244.09

Monetized Annual Benefits By Vehicle Type

Examining PCs and LTVs separately, as shown in Tables VI-7 and VI-8, IMA and LTA in PCs would save 1 to 3,707 fatal equivalents and $9.6 million to $36.0 billion, annually. The low estimates are for year 2022 when the app implementation starts. The high estimates are for the year 2054 when the V2V technology reaches full saturation among the on-road light vehicles and almost of these vehicles are equipped with the apps.

In parallel, the two apps in LTVs would save 1 to 3,933 equivalent lives and $9.6 million (lower bound for 2022) to $38.2 billion (higher bound for 2060). Note that the peak monetized value occurred in different year for PCs and LTVs is due to vehicle sale projections. When time progresses, the portion of LTVs among on-road operational light vehicles will be gradually increase and outweigh that of PCs. As a result, LTVs would have a relatively higher portion of the total annual benefits than do the PCs.

Table VI-7
Annual Monetized Benefits for **PCs**
(**Undiscounted**, 2014 $ in **Millions**)

	Calendar	Fatal Equivalents		Total Monetized Benefits		Property Damage and Congestion	
Year	Year	Low	High	Low	High	Low	High
1	2021	0.00	0.00	$0.00	$0.00	$0.00	$0.00
2	2022	0.99	1.29	$9.59	$12.50	$1.35	$1.80
3	2023	6.49	8.48	$63.03	$82.38	$8.84	$11.88
4	2024	25.96	33.93	$252.11	$329.50	$35.35	$47.50
5	2025	66.17	86.59	$642.56	$840.85	$90.09	$121.20
6	2026	139.94	183.56	$1,358.94	$1,782.45	$190.54	$256.88
7	2027	252.20	331.82	$2,449.00	$3,222.16	$343.41	$464.25
8	2028	389.38	513.83	$3,781.12	$4,989.63	$530.25	$718.73
9	2029	541.05	715.78	$5,253.99	$6,950.70	$736.86	$1,001.02
10	2030	704.69	934.15	$6,843.02	$9,071.19	$959.77	$1,306.19
11	2031	877.18	1165.02	$8,518.01	$11,313.11	$1,194.77	$1,628.77
12	2032	1055.86	1404.64	$10,253.04	$13,639.97	$1,438.21	$1,963.52
13	2033	1237.18	1648.39	$12,013.85	$16,006.90	$1,685.28	$2,303.97
14	2034	1418.91	1893.21	$13,778.56	$18,384.30	$1,932.91	$2,645.87
15	2035	1597.66	2134.54	$15,514.34	$20,727.79	$2,176.50	$2,982.84
16	2036	1769.63	2367.29	$17,184.25	$22,987.90	$2,410.87	$3,307.75
17	2037	1931.58	2586.93	$18,756.89	$25,120.74	$2,631.59	$3,614.32
18	2038	2080.83	2789.89	$20,206.24	$27,091.63	$2,835.03	$3,897.56
19	2039	2213.87	2971.37	$21,498.13	$28,853.90	$3,016.39	$4,150.75
20	2040	2329.99	3130.36	$22,625.75	$30,397.85	$3,174.70	$4,372.51

21	2041	2428.22	3265.40	$23,579.58	$31,709.19	$3,308.63	$4,560.80
22	2042	2502.07	3367.64	$24,296.73	$32,701.96	$3,409.35	$4,703.28
23	2043	2561.00	3449.60	$24,868.94	$33,497.82	$3,489.73	$4,817.45
24	2044	2606.41	3513.09	$25,309.92	$34,114.37	$3,551.68	$4,905.87
25	2045	2640.71	3561.21	$25,642.98	$34,581.70	$3,598.48	$4,972.87
26	2046	2666.85	3598.02	$25,896.82	$34,939.09	$3,634.15	$5,024.09
27	2047	2688.07	3627.83	$26,102.92	$35,228.61	$3,663.11	$5,065.60
28	2048	2704.66	3651.13	$26,263.98	$35,454.88	$3,685.74	$5,098.03
29	2049	2718.01	3669.91	$26,393.63	$35,637.27	$3,703.96	$5,124.18
30	2050	2728.69	3684.94	$26,497.36	$35,783.19	$3,718.53	$5,145.09
31	2051	2735.71	3694.92	$26,565.56	$35,880.12	$3,728.12	$5,158.98
32	2052	2740.62	3702.10	$26,613.23	$35,949.77	$3,734.83	$5,168.93
33	2053	2742.57	3705.22	$26,632.19	$35,980.14	$3,737.50	$5,173.25
34	2054	2743.26	3706.59	$26,638.86	$35,993.42	$3,738.45	$5,175.11
35	2055	2742.54	3705.96	$26,631.89	$35,987.31	$3,737.49	$5,174.19
36	2056	2740.70	3703.81	$26,613.98	$35,966.40	$3,734.98	$5,171.15
37	2057	2737.03	3699.13	$26,578.31	$35,921.01	$3,729.99	$5,164.59
38	2058	2731.80	3692.41	$26,527.57	$35,855.72	$3,722.88	$5,155.17
39	2059	2726.58	3685.69	$26,476.84	$35,790.44	$3,715.77	$5,145.75
40	2060	2721.78	3679.49	$26,430.22	$35,730.25	$3,709.23	$5,137.06

Table VI-8
Annual Monetized Benefits for **LTVs**
(Undiscounted, 2014 $ in **Millions**)

Year	Calendar Year	Fatal Equivalents		Total Monetized Benefits		Property Damage and Congestion	
		Low	High	Low	High	Low	High
1	2021	0.00	0.00	$0.00	$0.00	$0.00	$0.00
2	2022	0.99	1.29	$9.59	$12.50	$1.35	$1.80
3	2023	6.49	8.48	$63.03	$82.38	$8.84	$11.88
4	2024	24.97	32.65	$242.52	$317.01	$34.00	$45.70
5	2025	63.21	82.73	$613.78	$803.36	$86.05	$115.80
6	2026	133.45	175.07	$1,295.92	$1,700.07	$181.70	$245.00
7	2027	240.49	316.43	$2,335.31	$3,072.71	$327.47	$442.71
8	2028	370.76	489.25	$3,600.35	$4,750.91	$504.90	$684.35
9	2029	513.98	679.96	$4,991.08	$6,602.82	$699.99	$950.92
10	2030	668.60	886.32	$6,492.51	$8,606.75	$910.61	$1,239.32
11	2031	831.79	1104.72	$8,077.20	$10,727.52	$1,132.94	$1,544.47
12	2032	999.61	1329.81	$9,706.85	$12,913.34	$1,361.59	$1,858.92
13	2033	1169.38	1558.03	$11,355.47	$15,129.53	$1,592.92	$2,177.69
14	2034	1337.87	1785.05	$12,991.58	$17,334.00	$1,822.51	$2,494.71
15	2035	1501.82	2006.52	$14,583.69	$19,484.67	$2,045.94	$2,803.94
16	2036	1657.45	2217.18	$16,094.95	$21,530.27	$2,258.04	$3,098.02
17	2037	1802.78	2414.44	$17,506.15	$23,445.80	$2,456.11	$3,373.33
18	2038	1935.55	2595.08	$18,795.49	$25,199.89	$2,637.10	$3,625.40
19	2039	2053.38	2755.99	$19,939.67	$26,762.45	$2,797.72	$3,849.88
20	2040	2156.83	2897.75	$20,944.23	$28,139.07	$2,938.76	$4,047.60

21	2041	2246.19	3020.66	$21,811.95	$29,332.57	$3,060.60	$4,218.96
22	2042	2327.52	3132.66	$22,601.72	$30,420.22	$3,171.50	$4,375.11
23	2043	2397.72	3229.67	$23,283.42	$31,362.22	$3,267.24	$4,510.32
24	2044	2459.34	3314.83	$23,881.78	$32,189.19	$3,351.27	$4,629.02
25	2045	2512.94	3388.91	$24,402.27	$32,908.51	$3,424.37	$4,732.26
26	2046	2561.20	3455.47	$24,870.91	$33,554.88	$3,490.18	$4,825.05
27	2047	2605.38	3516.28	$25,299.97	$34,145.38	$3,550.43	$4,909.83
28	2048	2646.48	3572.62	$25,699.05	$34,692.51	$3,606.46	$4,988.41
29	2049	2684.91	3625.21	$26,072.20	$35,203.16	$3,658.85	$5,061.76
30	2050	2720.10	3673.28	$26,413.95	$35,669.94	$3,706.82	$5,128.82
31	2051	2750.92	3715.49	$26,713.27	$36,079.84	$3,748.85	$5,187.69
32	2052	2779.36	3754.42	$26,989.37	$36,457.85	$3,787.61	$5,241.99
33	2053	2804.83	3789.30	$27,236.76	$36,796.59	$3,822.35	$5,290.64
34	2054	2827.49	3820.37	$27,456.80	$37,098.34	$3,853.24	$5,333.98
35	2055	2847.76	3848.17	$27,653.61	$37,368.21	$3,880.87	$5,372.73
36	2056	2866.06	3873.20	$27,831.30	$37,611.29	$3,905.82	$5,407.65
37	2057	2881.68	3894.66	$27,982.99	$37,819.68	$3,927.12	$5,437.57
38	2058	2893.36	3910.79	$28,096.38	$37,976.30	$3,943.04	$5,460.06
39	2059	2902.78	3923.87	$28,187.89	$38,103.33	$3,955.90	$5,478.28
40	2060	2909.67	3933.43	$28,254.81	$38,196.18	$3,965.30	$5,491.60

C. Monetized MY Benefits

Monetized MY Benefits Of the Proposed Rule

The range of the monetized MY benefits (i.e., the lifetime benefits of a MYof vehicles) represents the estimates from both the “free-rider” and “no free-rider” approaches. The lower bound of the range represents the low estimate from the “free-rider” approach and upper bound represents the high estimate from the “no free-rider” approach. For each approach, the low and high estimates correspond to the low and high app effectiveness, respectively. Tables VI-9 and VI-10 show the monetized MY benefits at a 3 percent and 7 percent discount rate, respectively.

As shown, at a 3 percent discount rate, the MY 2022 vehicles would save 3 to 68 fatal equivalents and $33.8 to $659.0 million over their lifespan. MY 2050 vehicles would save a total of 3,350 to 5,608 fatal equivalents and $32.5 to $54.5 billion. The property damage and congestion savings would range from $4.7 to $94.9 million for the MY 2022 vehicles and $4.6 to $7.8 billion for the 2050 MY vehicles.

At a 7 percent discount rate, the MY 2022 vehicles would save 3 to 51 fatal equivalents and $31.8 to $497.0 million over their lifespan. MY 2050 vehicles would save a total 2,747 to 4,906 fatal equivalents and $26.7 to $47.6 billion. Of these monetized savings, the property damage and congestion savings are estimated to be $4.5 to $71.6 million for the MY 2022 vehicles and $3.7 to $6.8 billion for the 2050 MY vehicles.

Table VI-9
Monetized **MY** Benefits
(**@3 Percent** Discount, 2014 $ in **Millions**)

	Model	Fatal Equivalents		Total Monetized Benefits		Property Damage and Congestion	
Year	Year	Low	High	Low	High	Low	High
1	2021	0.00	0.00	$0.00	$0.00	$0.00	$0.00
2	2022	3.48	67.86	$33.79	$658.99	$4.74	$94.91
3	2023	23.35	208.55	$226.72	$2,025.12	$31.79	$291.65
4	2024	104.31	580.04	$1,012.92	$5,632.53	$142.02	$811.11
5	2025	257.57	1,017.05	$2,501.20	$9,876.22	$350.72	$1,422.05
6	2026	586.69	1,774.90	$5,697.12	$17,235.41	$798.94	$2,481.38
7	2027	1,112.42	2,621.45	$10,802.30	$25,455.98	$1,515.02	$3,664.44
8	2028	1,606.16	3,090.78	$15,596.91	$30,013.55	$2,187.63	$4,320.00
9	2029	1,946.18	3,250.93	$18,898.69	$31,568.66	$2,650.90	$4,543.36
10	2030	2,252.45	3,415.26	$21,872.79	$33,164.45	$3,068.24	$4,772.57
11	2031	2,523.52	3,563.63	$24,505.02	$34,605.22	$3,437.64	$4,979.46
12	2032	2,761.74	3,697.69	$26,818.31	$35,906.98	$3,762.58	$5,166.34
13	2033	2,847.78	3,975.69	$27,653.77	$38,606.57	$3,879.91	$5,555.21
14	2034	2,934.41	4,241.63	$28,495.06	$41,189.00	$3,998.06	$5,926.26
15	2035	3,009.61	4,475.08	$29,225.26	$43,456.01	$4,100.63	$6,251.90
16	2036	3,074.84	4,678.59	$29,858.67	$45,432.21	$4,189.61	$6,535.69
17	2037	3,134.46	4,858.86	$30,437.71	$47,182.69	$4,270.96	$6,787.01
18	2038	3,182.03	5,007.07	$30,899.56	$48,621.96	$4,335.86	$6,993.56
19	2039	3,224.93	5,139.68	$31,316.16	$49,909.68	$4,394.41	$7,178.33
20	2040	3,269.38	5,267.60	$31,747.87	$51,151.88	$4,455.07	$7,356.56
21	2041	3,320.90	5,404.46	$32,248.10	$52,480.81	$4,525.34	$7,547.30
22	2042	3,224.76	5,283.11	$31,314.49	$51,302.48	$4,394.39	$7,377.52
23	2043	3,241.75	5,334.51	$31,479.52	$51,801.61	$4,417.60	$7,449.02
24	2044	3,258.96	5,380.31	$31,646.62	$52,246.36	$4,441.10	$7,512.74
25	2045	3,275.27	5,423.17	$31,805.05	$52,662.57	$4,463.36	$7,572.40
26	2046	3,290.63	5,461.25	$31,954.16	$53,032.36	$4,484.32	$7,625.42
27	2047	3,306.52	5,499.93	$32,108.44	$53,407.94	$4,505.99	$7,679.31
28	2048	3,319.75	5,536.44	$32,236.99	$53,762.45	$4,524.05	$7,730.18
29	2049	3,333.27	5,571.05	$32,368.22	$54,098.58	$4,542.49	$7,778.42
30	2050	3,350.10	5,608.31	$32,531.65	$54,460.39	$4,565.44	$7,830.37

Table VI-10
Monetized **MY** Benefits
(@7 Percent Discount, 2014 $ in **Millions**)

Year	Model Year	Fatal Equivalents		Total Monetized Benefits		Property Damage and Congestion	
		Low	High	Low	High	Low	High
1	2021	0.00	0.00	$0.00	$0.00	$0.00	$0.00
2	2022	3.28	51.18	$31.80	$497.03	$4.46	$71.59
3	2023	21.83	159.55	$212.00	$1,549.29	$29.72	$223.15
4	2024	96.35	450.18	$935.65	$4,371.50	$131.19	$629.59
5	2025	234.85	795.52	$2,280.53	$7,725.00	$319.78	$1,112.43
6	2026	527.59	1,396.62	$5,123.26	$13,562.13	$718.45	$1,952.75
7	2027	989.03	2,077.54	$9,604.09	$20,174.30	$1,346.94	$2,904.40
8	2028	1,416.94	2,459.15	$13,759.41	$23,879.93	$1,929.87	$3,437.45
9	2029	1,710.25	2,598.90	$16,607.61	$25,236.98	$2,329.50	$3,632.38
10	2030	1,974.86	2,741.45	$19,177.23	$26,621.24	$2,690.07	$3,831.23
11	2031	2,149.18	2,947.24	$20,869.91	$28,619.59	$2,927.85	$4,119.15
12	2032	2,233.37	3,227.88	$21,687.48	$31,344.84	$3,042.66	$4,510.89
13	2033	2,309.61	3,478.57	$22,427.83	$33,779.21	$3,146.63	$4,860.73
14	2034	2,385.57	3,711.72	$23,165.40	$36,043.23	$3,250.21	$5,186.03
15	2035	2,451.89	3,916.19	$23,809.50	$38,028.75	$3,340.68	$5,471.24
16	2036	2,509.12	4,095.07	$24,365.23	$39,765.77	$3,418.75	$5,720.68
17	2037	2,562.08	4,254.99	$24,879.46	$41,318.79	$3,490.99	$5,943.64
18	2038	2,602.73	4,384.79	$25,274.25	$42,579.22	$3,546.47	$6,124.52
19	2039	2,640.12	4,501.23	$25,637.28	$43,709.92	$3,597.49	$6,286.75
20	2040	2,678.06	4,613.37	$26,005.75	$44,798.85	$3,649.27	$6,442.98
21	2041	2,720.95	4,730.53	$26,422.20	$45,936.55	$3,707.77	$6,606.25
22	2042	2,641.60	4,624.69	$25,651.68	$44,908.74	$3,599.70	$6,458.14
23	2043	2,656.70	4,670.32	$25,798.30	$45,351.86	$3,620.32	$6,521.61
24	2044	2,670.51	4,709.04	$25,932.43	$45,727.85	$3,639.18	$6,575.46
25	2045	2,685.53	4,747.17	$26,078.29	$46,098.16	$3,659.68	$6,628.54
26	2046	2,696.56	4,779.45	$26,185.33	$46,411.61	$3,674.73	$6,673.47
27	2047	2,711.29	4,815.03	$26,328.44	$46,757.14	$3,694.84	$6,723.04
28	2048	2,721.94	4,845.29	$26,431.78	$47,050.95	$3,709.36	$6,765.20
29	2049	2,734.33	4,873.87	$26,552.13	$47,328.48	$3,726.26	$6,805.02
30	2050	2,747.06	4,905.91	$26,675.71	$47,639.58	$3,743.62	$6,849.69

Monetized MY Benefits by Apps

Tables VI-11 and VI-12 present the MY benefits are for IMA at a 3 percent and 7 percent discount rate, respectively. In parallel, Tables VI-13 and VI-14 show the same information for LTA. As shown, at a 3 percent discount rate, the IMA app in MY 2022 would save 3 to 52 fatal equivalents and \$28.9 to \$505.5 million over the vehicles' lifespan. Of these monetized savings, \$4.0 to \$73.2 million are property damage and congestion savings. The IMA app in MY 2050 vehicles would save 2,530 to 3,881 fatal equivalents. These savings when translating into monetized value range from \$24.6 to \$37.7 billion. Of the saved amounts, \$3.4 to \$5.5 billion are property damage and congestion savings.

At a 7 percent discount rate, the IMA app in MY 2022 would save 3 to 40 fatal equivalents and \$27.2 to \$384.0 million over the vehicles' lifespan. Of these monetized savings, \$3.8 to \$55.6 million are property damage and congestion savings. The IMA app in MY 2050 vehicles would save 2,075 to 3,396 fatal equivalents. The monetized value of these savings would range from \$20.2 to \$33.0 billion. Of the saved amounts, \$2.8 to \$4.8 billion are property damage and congestion savings.

In contrast, at a 3 percent discount rate, the LTA app installed in the MY 2022 vehicles would save about 1 to 16 fatal equivalents over vehicles' life. The monetized value of these benefits is estimated to be \$4.9 to \$153.5 million. Of the saved amounts, \$0.7 to \$21.7 million are property damage and congestion savings. The 2050 MY vehicles would all have LTA. These vehicles would save 820 to 1,727 fatal equivalents. These benefits would result a total of \$8.0 to \$16.8 billion savings to the society, \$1.1 to \$2.4 billion would come from property damage and congestion savings.

At a 7 percent discount rate, the LTA app installed in the MY 2022 vehicles would save up to 12 fatal equivalents over vehicles' life. The monetized value of these benefits would range from \$4.6 to \$113.1 million. Of these savings, \$0.7 to \$16.0 million are property damage and congestion savings. When all vehicles had LTA as did the 2050 MY vehicles, over its lifespan, 672 to 1,510 fatal equivalents would be saved. These benefits resulted in a total of \$6.5 to \$14.7

billion savings to the society. Of these savings, $923.1 million to $2.1 billion would be property damage and congestion savings.

Table VI-11
Monetized MY Benefits for **IMA**
(**@3 Percent** Discount, 2014 $ in **Millions**)

Year	Model Year	Fatal Equivalents		Total Monetized Benefits		Property Damage and Congestion	
		Low	High	Low	High	Low	High
1	2021	0.00	0.00	$0.00	$0.00	$0.00	$0.00
2	2022	2.97	52.05	$28.86	$505.45	$4.04	$73.19
3	2023	19.75	159.14	$191.80	$1,545.32	$26.85	$223.77
4	2024	87.65	440.33	$851.16	$4,275.85	$119.14	$619.16
5	2025	214.44	767.12	$2,082.34	$7,449.26	$291.47	$1,078.68
6	2026	482.99	1,329.29	$4,690.15	$12,908.25	$656.48	$1,869.16
7	2027	905.96	1,949.15	$8,797.47	$18,927.55	$1,231.39	$2,740.78
8	2028	1,296.49	2,282.53	$12,589.82	$22,164.90	$1,762.21	$3,209.56
9	2029	1,559.67	2,385.99	$15,145.46	$23,169.49	$2,119.93	$3,355.03
10	2030	1,794.08	2,492.36	$17,421.70	$24,202.48	$2,438.53	$3,504.61
11	2031	1,998.93	2,586.78	$19,410.94	$25,119.34	$2,716.97	$3,637.37
12	2032	2,158.52	2,693.97	$20,960.68	$26,160.23	$2,933.89	$3,788.10
13	2033	2,217.49	2,885.38	$21,533.33	$28,018.97	$3,014.04	$4,057.25
14	2034	2,276.92	3,061.57	$22,110.36	$29,729.87	$3,094.81	$4,304.99
15	2035	2,327.52	3,213.52	$22,601.74	$31,205.42	$3,163.59	$4,518.66
16	2036	2,370.55	3,343.59	$23,019.55	$32,468.44	$3,222.07	$4,701.55
17	2037	2,409.48	3,456.87	$23,397.61	$33,568.52	$3,274.99	$4,860.84
18	2038	2,439.42	3,547.46	$23,688.39	$34,448.17	$3,315.69	$4,988.22
19	2039	2,466.15	3,627.28	$23,947.90	$35,223.24	$3,352.01	$5,100.45
20	2040	2,494.51	3,704.40	$24,223.32	$35,972.19	$3,390.56	$5,208.90
21	2041	2,528.77	3,788.66	$24,555.98	$36,790.32	$3,437.13	$5,327.37
22	2042	2,451.32	3,693.50	$23,803.93	$35,866.30	$3,331.86	$5,193.57
23	2043	2,460.64	3,720.79	$23,894.47	$36,131.27	$3,344.53	$5,231.94
24	2044	2,470.72	3,745.58	$23,992.34	$36,372.00	$3,358.23	$5,266.80
25	2045	2,480.66	3,769.60	$24,088.82	$36,605.32	$3,371.74	$5,300.58
26	2046	2,490.30	3,791.39	$24,182.49	$36,816.85	$3,384.85	$5,331.21
27	2047	2,500.70	3,814.46	$24,283.41	$37,040.94	$3,398.97	$5,363.66
28	2048	2,509.35	3,836.67	$24,367.42	$37,256.61	$3,410.73	$5,394.89
29	2049	2,518.38	3,857.98	$24,455.10	$37,463.51	$3,423.01	$5,424.85
30	2050	2,530.04	3,881.41	$24,568.36	$37,690.99	$3,438.86	$5,457.79

Table VI-12
Monetized MY Benefits for **IMA**
(**@7 Percent** Discount, 2014 $ in **Millions**)

Year	Model Year	Fatal Equivalents		Total Monetized Benefits		Property Damage and Congestion	
		Low	High	Low	High	Low	High
1	2021	0.00	0.00	$0.00	$0.00	$0.00	$0.00
2	2022	2.80	39.54	$27.19	$383.95	$3.81	$55.60
3	2023	18.49	122.64	$179.53	$1,190.92	$25.13	$172.45
4	2024	81.09	344.16	$787.42	$3,342.04	$110.22	$483.94
5	2025	195.91	604.09	$1,902.43	$5,866.11	$266.29	$849.43
6	2026	435.30	1,052.50	$4,227.09	$10,220.44	$591.67	$1,479.96
7	2027	807.21	1,553.26	$7,838.54	$15,083.17	$1,097.17	$2,184.10
8	2028	1,146.09	1,825.18	$11,129.28	$17,723.74	$1,557.78	$2,566.46
9	2029	1,373.17	1,916.08	$13,334.41	$18,606.43	$1,866.43	$2,694.28
10	2030	1,575.74	2,008.95	$15,301.51	$19,508.18	$2,141.77	$2,824.85
11	2031	1,691.41	2,169.80	$16,424.69	$21,070.18	$2,298.98	$3,051.04
12	2032	1,750.37	2,361.06	$16,997.21	$22,927.45	$2,379.12	$3,319.98
13	2033	1,802.98	2,529.17	$17,508.14	$24,559.86	$2,450.63	$3,556.36
14	2034	1,855.34	2,683.61	$18,016.55	$26,059.59	$2,521.80	$3,773.52
15	2035	1,900.19	2,816.59	$18,452.07	$27,350.98	$2,582.76	$3,960.52
16	2036	1,938.09	2,930.79	$18,820.09	$28,459.88	$2,634.27	$4,121.09
17	2037	1,972.83	3,031.22	$19,157.45	$29,435.17	$2,681.49	$4,262.32
18	2038	1,998.32	3,110.26	$19,405.02	$30,202.68	$2,716.14	$4,373.46
19	2039	2,021.58	3,180.03	$19,630.83	$30,880.15	$2,747.75	$4,471.56
20	2040	2,045.62	3,247.26	$19,864.32	$31,533.01	$2,780.43	$4,566.09
21	2041	2,073.87	3,318.78	$20,138.61	$32,227.50	$2,818.82	$4,666.66
22	2042	2,009.61	3,235.26	$19,514.62	$31,416.45	$2,731.48	$4,549.22
23	2043	2,017.87	3,259.21	$19,594.80	$31,649.10	$2,742.70	$4,582.90
24	2044	2,025.68	3,279.65	$19,670.73	$31,847.52	$2,753.33	$4,611.64
25	2045	2,034.90	3,300.86	$19,760.23	$32,053.52	$2,765.86	$4,641.46
26	2046	2,041.49	3,319.01	$19,824.23	$32,229.79	$2,774.82	$4,666.99
27	2047	2,051.21	3,340.27	$19,918.59	$32,436.25	$2,788.03	$4,696.89
28	2048	2,058.07	3,358.45	$19,985.19	$32,612.73	$2,797.35	$4,722.44
29	2049	2,066.40	3,375.84	$20,066.10	$32,781.63	$2,808.67	$4,746.90
30	2050	2,075.10	3,395.90	$20,150.56	$32,976.39	$2,820.49	$4,775.10

Table VI-13
Monetized MY Benefits for **LTA**
(**@3 Percent** Discount, 2014 $ in **Millions**)

Year	Model Year	Fatal Equivalents		Total Monetized Benefits		Property Damage and Congestion	
		Low	High	Low	High	Low	High
1	2021	0.00	0.00	$0.00	$0.00	$0.00	$0.00
2	2022	0.51	15.81	$4.93	$153.53	$0.70	$21.72
3	2023	3.60	49.41	$34.92	$479.79	$4.94	$67.88
4	2024	16.66	139.71	$161.76	$1,356.68	$22.88	$191.95
5	2025	43.13	249.93	$418.86	$2,426.96	$59.26	$343.37
6	2026	103.70	445.61	$1,006.97	$4,327.16	$142.46	$612.22
7	2027	206.46	672.30	$2,004.82	$6,528.44	$283.63	$923.66
8	2028	309.67	808.25	$3,007.10	$7,848.65	$425.42	$1,110.45
9	2029	386.51	864.94	$3,753.23	$8,399.17	$530.98	$1,188.34
10	2030	458.37	922.90	$4,451.09	$8,961.97	$629.70	$1,267.96
11	2031	524.59	976.85	$5,094.08	$9,485.88	$720.67	$1,342.09
12	2032	585.15	1,027.01	$5,682.14	$9,972.98	$803.86	$1,411.00
13	2033	630.28	1,090.31	$6,120.44	$10,587.60	$865.87	$1,497.96
14	2034	657.49	1,180.06	$6,384.70	$11,459.14	$903.25	$1,621.27
15	2035	682.09	1,261.56	$6,623.52	$12,250.59	$937.04	$1,733.24
16	2036	704.29	1,335.00	$6,839.11	$12,963.77	$967.54	$1,834.15
17	2037	724.99	1,401.98	$7,040.09	$13,614.17	$995.97	$1,926.17
18	2038	742.60	1,459.61	$7,211.17	$14,173.78	$1,020.17	$2,005.34
19	2039	758.78	1,512.41	$7,368.26	$14,686.45	$1,042.40	$2,077.88
20	2040	774.88	1,563.20	$7,524.55	$15,179.69	$1,064.51	$2,147.66
21	2041	792.13	1,615.80	$7,692.13	$15,690.49	$1,088.22	$2,219.93
22	2042	773.44	1,589.61	$7,510.56	$15,436.18	$1,062.53	$2,183.95
23	2043	781.11	1,613.73	$7,585.05	$15,670.34	$1,073.07	$2,217.08
24	2044	788.24	1,634.74	$7,654.28	$15,874.36	$1,082.86	$2,245.95
25	2045	794.61	1,653.57	$7,716.22	$16,057.25	$1,091.62	$2,271.82
26	2046	800.32	1,669.87	$7,771.67	$16,215.51	$1,099.47	$2,294.21
27	2047	805.82	1,685.47	$7,825.03	$16,367.00	$1,107.02	$2,315.65
28	2048	810.41	1,699.77	$7,869.56	$16,505.84	$1,113.32	$2,335.29
29	2049	814.89	1,713.07	$7,913.12	$16,635.07	$1,119.48	$2,353.57
30	2050	820.06	1,726.91	$7,963.30	$16,769.40	$1,126.58	$2,372.58

Table VI-14
Monetized MY Benefits for **IMA**
(**@7 Percent** Discount, 2014 $ in **Millions**)

Year	Model Year	Fatal Equivalents		Total Monetized Benefits		Property Damage and Congestion	
		Low	High	Low	High	Low	High
1	2021	0.00	0.00	$0.00	$0.00	$0.00	$0.00
2	2022	0.48	11.65	$4.62	$113.08	$0.65	$16.00
3	2023	3.34	36.90	$32.47	$358.37	$4.59	$50.70
4	2024	15.26	106.01	$148.23	$1,029.46	$20.97	$145.65
5	2025	38.94	191.43	$378.10	$1,858.89	$53.49	$263.00
6	2026	92.29	344.13	$896.17	$3,341.69	$126.78	$472.79
7	2027	181.82	524.28	$1,765.55	$5,091.13	$249.77	$720.31
8	2028	270.85	633.96	$2,630.13	$6,156.18	$372.09	$870.99
9	2029	337.07	682.81	$3,273.21	$6,630.54	$463.07	$938.11
10	2030	399.12	732.50	$3,875.72	$7,113.07	$548.30	$1,006.37
11	2031	456.63	779.38	$4,434.14	$7,568.25	$627.30	$1,070.78
12	2032	483.00	866.82	$4,690.27	$8,417.39	$663.54	$1,190.91
13	2033	506.63	949.40	$4,919.69	$9,219.34	$696.00	$1,304.38
14	2034	530.23	1,028.11	$5,148.85	$9,983.63	$728.42	$1,412.51
15	2035	551.71	1,099.59	$5,357.43	$10,677.77	$757.92	$1,510.72
16	2036	571.04	1,164.28	$5,545.14	$11,305.88	$784.48	$1,599.59
17	2037	589.25	1,223.77	$5,722.00	$11,883.61	$809.50	$1,681.32
18	2038	604.41	1,274.53	$5,869.23	$12,376.54	$830.33	$1,751.07
19	2039	618.54	1,321.21	$6,006.45	$12,829.77	$849.74	$1,815.19
20	2040	632.44	1,366.11	$6,141.43	$13,265.85	$868.84	$1,876.89
21	2041	647.08	1,411.75	$6,283.59	$13,709.05	$888.95	$1,939.59
22	2042	631.99	1,389.43	$6,137.05	$13,492.29	$868.22	$1,908.92
23	2043	638.83	1,411.11	$6,203.50	$13,702.76	$877.62	$1,938.70
24	2044	644.83	1,429.39	$6,261.70	$13,880.34	$885.85	$1,963.83
25	2045	650.63	1,446.31	$6,318.06	$14,044.65	$893.83	$1,987.07
26	2046	655.06	1,460.44	$6,361.10	$14,181.81	$899.91	$2,006.48
27	2047	660.08	1,474.76	$6,409.85	$14,320.90	$906.81	$2,026.16
28	2048	663.87	1,486.84	$6,446.59	$14,438.22	$912.01	$2,042.76
29	2049	667.93	1,498.03	$6,486.03	$14,546.85	$917.59	$2,058.13
30	2050	671.96	1,510.01	$6,525.15	$14,663.19	$923.12	$2,074.59

CHAPTER VII. COSTS

This chapter quantifies the costs of the proposed rule and discusses non-quantified costs. The costs of the proposed rule are based on the primary proposals for message authentication and misbehavior reporting based on SCMS and include the cost for (1) DSRC radios and relevant in-vehicle components and hardware security module (HSM) for enabling a secure communication among vehicles, (2) two apps (IMA and LTA), (3) other in-vehicle components primarily for supporting the communication between vehicles and SCMS, (4) the communication network (e.g., cellular, Wi-Fi, and satellite) for the communication between vehicles and SCMS, (5) non in-vehicle equipment also for vehicle-to-SCMS communication, (6) SCMS costs, and (7) the fuel economy impact due to the added weight from the in-vehicle equipment from (1) and (3) above. Of these seven items, the first two costs, DSRC radios and apps were categorized as vehicle equipment cost, items (3) to (5) were vehicles-to-SCMS communication related costs and were categorized as communication cost. With the remaining two costs, the cost of the proposed rule comprised four parts: vehicle equipment, communication, SCMS, and fuel economy impact. Costs for the performance-based message authentication and the no message authentication alternative are not addressed in this section. In addition, costs for the no misbehavior reporting alternative are also not discussed in this section.

To correspond to benefit estimates, the costs also were presented in two measures: annual costs and costs by MY vehicles (MY costs). The annual costs represent the yearly financial commitment on vehicle equipment, communication, and SCMS plus the annual fuel economy impact. The MY costs, as the name indicated, are MY based costs representing the total investment born by MY vehicles plus the lifetime fuel economy impact from those MY vehicles. The PRIA assumed that vehicle equipment, communication, and SCMS costs were paid by new vehicle owners when their vehicles were purchased. Therefore, these three costs are identical for both cost measures. The only difference between the two cost measures is fuel economy impact. The annual fuel economy impact measures the collective fuel impact from all V2V-equipped vehicles for a specific calendar year. In contrast, the lifetime fuel economy impact measures the fuel impact specifically for a MY vehicle through its operational life.

The agency considers two technology implementation approaches that can meet the safety, security, and privacy requirements of the proposed rule. These two approaches are (1) one DSRC radio pairing with a hybrid of communication protocol that included cellular, Wi-Fi, and Satellite (one-radio approach) and (2) two DSRC radios pairing with a DSRC-exclusive communication protocol (two-radio approach). As a result, both the annual and MY costs are presented as a range which covers the costs from these two approaches. Furthermore, in this analysis, a MY vehicle production represents the new vehicle production volume for the calendar year with the same number and the volume used as the basis for estimating the annual costs for that specific calendar year. For example, MY 2021 vehicle production volume is used to estimate the costs for 2021.

The following four sections describe the four parts of quantified costs and are followed by the summary of the total quantified costs and non-quantified costs. In addition to the total costs, the PRIA also presents cost per vehicle. This normalized per vehicle cost allows a straightforward comparison between various technology approaches and regulatory alternatives. All costs were estimated under the DSRC and app sales scenario that was specified in the Benefits chapter. All costs are in 2014 dollars.

A. Vehicle Equipment Costs

The vehicle equipment costs included the costs of DSRC radios, DSRC antenna, GPS, HSM, and installation relevant equipment (DSRC radios in short) and safety apps from the Original Equipment Manufacturers (OEM) including the driver-vehicle interface (DVI). The OEM DSRC radios are an integrated safety system that will be built into vehicles during their manufacture. The integrated system is connected to proprietary data buses and can provide highly accurate information using in-vehicle sensors to generate the BSM. The DSRC radios can both broadcast and receive BSMs and can process the content of received messages. The received BSMs can be used by apps to provide warnings and/or alerts to the driver of the vehicle in which the apps are installed. GPS provides the relative position of the vehicles. This GPS information is an element of BSMs. HSM ensures temper proofing and safeguarding of the certificate. Apps are software that can triage the BSMs and issue warnings. App costs include software engineering and development costs since the agency is not assuming any additional interface beyond the DVI or equipment costs for the apps. The variable costs of the above component to the OEMs are estimated first. These variable costs then were used to estimate the cost to consumers.

A.1 Variable Costs to OEMs

The variable costs are the direct material and labor of producing in-vehicleV2V components. The in-vehicle components include DSRC radios, DSRC antenna, a GPS receiver, and a processor to derive information such as vehicle speed and predicted path from the device's GPS data. Access to an inertial measurement unit to detect acceleration forces would improve the quality of the data that apps could use to issue warnings. If they are going to support safety applications that warn drivers of danger, V2V devices also require a means to issue a warning to the driver through a driver-vehicle interface (DVI). The warning could be audible or visual (and requires corresponding hardware). For devices fully integrated into the vehicle at the time of manufacture, vehicles with Integrated Safety Systems could potentially provide haptic warnings to alert the driver such as tightening the seat belt or vibrating the driver's seat as well.

Our component cost estimates to OEMs when they are purchasing supplies are based on confidential information provided by two suppliers. The ANPRM reported the initial component cost estimates in 2012 dollars for two DSRC radios. The PRIA revised the costs from 2012 dollars to 2014 dollars by applying the Implicit Price Deflector for Gross Domestic Product (GDP) of 1.033 (= 108.686/105.214) to the costs in 2012 dollars.[111] In addition, the PRIA included the costs from hardware security module (HSM) and the software costs of the two apps. HSM is a computer chip that is needed to ensure the security of the certificates. It is about 10 percent of the cost of electronic control unit (ECU) with negligible weight. Table VII-1 shows the component unit weight in pounds (lbs) and the revised unit costs in 2014 dollars. The weight will be used to determine the fuel impacts of these additional weights.

[111] Published by the Bureau of Economic Analysis within the Bureau of Labor Statistics as of April 29, 2015

As shown, the total direct component costs to OEMs were estimated to be $162.77 for one DSRC radio and $229.91 for two radios. The total weight of one DSRC radio is approximately 2.91 lbs whereas the weight of two radios is slightly heavier, about 3.23 lbs. For the two-radio approach, as previously discussed, two DSRC antennas are necessary: The first DSRC radio sends and receives the BSM, and the second radio handles security aspects of receiving certificates, the certificate revocation list, etc. We estimated that the second radio will be $10.33[112] cheaper than the first radio since these two radios would most likely be packaged together, thereby resulting in lower labor costs in assembling the combined package at the supplier, as well as lower hardware costs in packaging them together rather than individually. Therefore, the cost for two radios would be $134.29 (=$72.31 * 2 – $10.33) instead of $144.62 (=$72.31 *2), as shown in Table VII-1. No such assumption was made for the antenna, since the antennas have to remain physically separate in order to avoid interfering with each other.

Table VII-1

Estimated Component Unit Weight and Costs to OEMs

Component	Costs	One Radio		Two Radios	
	(2012 $)	Weight (lbs)	Costs (2014 $)	Weight (lbs)	Costs (2014 $)
DSRC Transmitter/Receiver	$70	0.55	$72.31	0.65	$134.29
DSRC Antenna	$5	0.22	$5.17	0.44	$10.33
Electronic Control Unit	$45	0.55	$46.49	0.55	$46.49
GPS	$14		$14.46		$14.46
GPS Antenna	$4	0.22	$4.13	0.22	$4.13
Wiring	$9	1.20	$9.30	1.20	$9.30
Displays	$4.79	0.17	$4.95	0.17	$4.95
HSM		0.00	$4.65	0.00	$4.65
For 2 Apps		0.00	$1.32	0.00	$1.32
Total	$151.79	2.91	$162.77	3.23	$229.91

As explained in the ANPRM, the variable costs to OEMs were based on data received from two suppliers in response to a voluntary request for cost information sent to eight suppliers of V2V equipment. We note that low volume sales result in very high initial prices. If each responding supplier had picked a different volume of sales, the responses would not have been easily comparable. In order to ensure consistent production estimates, we asked the suppliers to

[112] Adjusted from the $10 in 2011 dollars that was estimated in the ANPRM

prepare their cost estimates based upon the assumption of high-volume production (i.e., at least 250,000 sales per make/model). The high-volume production cost was used to estimate the cost of the proposed rule. The high-volume assumption helped us to ensure consistent estimates across suppliers who responded. In addition to the high-volume assumption, assumptions regarding the learning curve will be applied later in the analysis.

We made several adjustments to the information we received from the two suppliers to arrive at the above estimates. First, the agency has changed some of its assumptions since requesting information from these suppliers (e.g., we now believe that two DSRC radios and two DSRC antennas are necessary, rather than one DSRC radio and one DSRC antenna). Second, the suppliers provided estimates relating to costs of equipment they supplied, but these estimates did not necessarily include costs for driver warnings for the safety applications that would use V2V, nor did they include labor and wiring necessary for the OEM to install the equipment into the vehicle. The information from the suppliers was thus incomplete for our current purposes, and more assumptions were needed in order to provide a more complete estimate of costs.

A.2 Component Consumer costs

The costs in Table VII-1 show the costs that OEMs pay to the supplier to purchase these components (i.e., variable costs), not the cost of these systems to consumers. To obtain the consumer costs, each variable cost is multiplied by 1.51 (i.e., 51 percent markup) to estimate a retail price equivalent (RPE; i.e., consumer cost). The 51 percent markup represents fixed costs (research and development, selling and administrative costs, etc.), as well as OEM profits, transportation costs, and dealer costs and profits. Table VII-2 presents the component consumer costs. As shown, the total component costs to OEMs were estimated to be $245.79 for one radio and $347.18 for two radios. Additional costs to consumers (e.g., installation costs) are estimated separately and further discussed later.

Table VII-2
Estimated Component Consumer Unit Costs
(2014 $)

Component	One Radio	Two Radios
DSRC Transmitter/Receiver	$109.19	$202.78
DSRC Antenna	$7.80	$15.60
Electronic Control Unit	$70.19	$70.19
GPS	$21.84	$21.84
GPS Antenna	$6.24	$6.24
Wiring	$14.04	$14.04
Displays	$7.47	$7.47
HSM	$7.02	$7.02
2 Apps	$2.00	$2.00
Total	$245.79	$347.18

Note that cost information gathered for displays included both manufacturer-produced and supplier-provided displays and for different types of displays (e.g., display lights, malfunction lights) that can be used by the safety applications to inform drivers of potential dangers identified by V2V communications. The display cost was estimated to be $7.47 which included the costs of malfunction lights, display lights, and a light bar. This cost was adjusted to 2014 value from the estimates presented in the NPRM for 5 display lights and 5 malfunction lights. In the PRIA, we determine that 2 display lights and 2 malfunction lights are needed, instead of 5 display lights and 5 malfunction lights. However, the PRIA did not scale the costs (associated 5 display lights and 5 malfunction lights) down to reflect 2 display lights and 2 malfunction light since these costs would account for less than 0.5 percent of the component costs and would not significantly impact the cost estimates. Furthermore, the display cost estimates were derived by assuming that the manufacturers would use the existing audible warning equipment already in the vehicle when all applicable vehicles are required to have the proposed V2V. Finally, if manufacturers chose to use a haptic system with and without an audible system, in general, the cost would be higher than the estimates we have included in this analysis.

A.3 Installation costs

The main installation cost is labor, but there are also costs associated with materials used in the installation of the vehicle equipment (e.g., minor attachments such as brackets or plastic tie downs to secure wires, etc.). In the table below, the installation costs are separated into "Material Costs" (for the minor attachments), "Labor Costs," and "Variable Burden" (i.e., other costs that are not direct labor or direct material used in the part, but are costs that vary with the level of production, such as set-up costs, in-bound freight, perishable production tools, and electricity). We estimated that the variable cost to OEMs to install the V2V equipment is $11.79 per vehicle and that the cost to consumers will be $17.80 with the 1.51 RPE. The weight of the installation materials was estimated to be 0.26 pound per vehicle.

Table VII-3
Consumer Installation Cost Estimates (2014 dollars)

Part	Material Cost	Labor Cost	Variable Burden	Total Variable	Total Consumer Cost
DSRC Transmitter/Receiver	0.04	1.61	1.04	2.69	4.06
DSRC Antenna	0.04	0.10	0.07	0.21	0.31
Electronic Control Unit	0.02	1.84	1.19	3.05	4.60
GPS	0.04	0.10	0.07	0.21	0.31
GPS Antenna	0.04	0.10	0.07	0.21	0.31
Wiring	0.19	0.93	0.60	1.72	2.59
Five Displays + Malfunction Disp.	0.00	0.63	0.40	1.03	1.56
Light Bar	0.04	1.61	1.04	2.69	4.06
HSM	0.00	0.00	0.00	0.00	0.00
Total	0.38	6.92	4.48	11.79	17.80

The initial installation costs were taken from a 2012 report entitled "Cost, Weight & Lead Time Analysis of Lane Departure Warning Systems and Lane Keeping Systems Technology Associated with Passenger Vehicles" by Lieberman & Associates. The report estimated the costs for installing back-up systems (e.g., a camera, ECU, displays) from six different make/models of vehicles. While the parts are not the same, we believe that the process for installing these parts would have similar material, labor, and variable burden costs (e.g., the V2V system uses a DSRC radio instead of a camera) since both V2V and back-up camera manufacturers receive these components from suppliers and install the systems using similar tools. The cost estimates in the report are in 2011 dollars. The costs were multiplied by the GDP deflator of 1.052 (= 108.686/103.311) to bring them up to 2014 dollars.

In addition to using the cost estimates from the Lieberman study, a few assumptions were made to estimate the installation costs. For wiring, we assumed a variable labor cost of $21.14 per hour. The labor cost was based on an assumption that these new wires would be combined with other wiring harnesses. Under the assumption, the incremental cost would be the (labor) time to identify and hook up the wires. We determined that it would take 10 seconds per wire to hook up both ends and that a total of 15 separate wires would need to be installed (seven for displays and malfunction lamp and eight between the two DSRC radios, two DSRC antenna, GPS, GPS antenna, amplifier, and ECU).

A.4 Adjustment for GPS Installation

The major factor that would influence the component costs discussed above is the GPS installation rate. While the supplier costs and the installation costs are incurred in order to install the components necessary to support V2V safety applications, many vehicles are already being equipped with GPS units. For those vehicles, the GPS component of the V2V system is not a cost that is attributable to the V2V system, since the current information available to the agency indicates that navigation-grade GPS units are sufficient for the V2V safety applications.

Based on Ward's Automotive Yearbook 2014, NHTSA estimates that about 43 percent of 2013 MY light vehicle fleet has GPS (and a GPS antenna). This estimate is based on vehicles with factory-installed navigation systems or concierge systems. There were about 6.1 million out of total 14.2 million vehicles had these systems. This estimate is lower than the 50 percent that was estimated in the ANPRM. Since this does not include OEM Automatic Collision Notification (ACN) systems which have GPS as part of the systems and the projection should be at the 2011 level, the PRIA still used the 50 percent as the base for GPS installation. In other words, 50 percent of applicable vehicles would not need to spend additional money on GPS for V2V. Thus, the total cost associated with vehicles equipped with GPS (i.e., 50%) was subtracted from the total costs of equipping all applicable vehicles with V2V safety applications.

A.5 Summary of V2V Component Costs

Table VII-4 summarizes consumer costs for original equipment manufacturers (OEMs) for the first year. The consumer unit cost is estimated to be $249.19 for one radio and $350.57 for two radios in 2014 dollars. The costs are expected to decrease over time based on the learning factor which takes into account the potential cost savings that manufacturers will realize due to their progressive experience manufacturing the product.

Table VII-4
Summary of V2V Component Consumer Costs and Weight
(2014 $)

Cost Items	**One Radio**		**Two-Radios**	
	Weight (lb.)	Consumer Costs	Weight (lb.)	Consumer Costs
Parts*	2.91	$245.79	3.23	$347.18
Installation	0.26	$17.74	0.26	$17.74
Subtotal	3.17	$263.53	3.49	$364.92
Minus Current GPS Installation**	0.11	$14.35	0.11	$14.35
Total	3.06	$249.18	3.38	$350.57

*including app software costs
** taking into account the 50 percent GPS installation rate

A.6 Learning Curve Effect

As manufacturers gain experience through production of the same product, they refine production techniques, raw material and component sources, and assembly methods to maximize efficiency and thus reduce production unit costs. Learning curves reflect the impact of experience and volume on the cost of production. V2V systems are expected to be installed on a growing portion of the vehicle fleet as manufacturers ramp up to the meet the proposed rule which would require 100% new vehicle installation by 2023. This amounts to a total of over 16 million units annually. This large scale production provides manufacturers with opportunities to reduce system costs through the learning process.

The method commonly mentioned in the literature estimates the rate of change in average cost as a function of cumulative output. Essentially, each doubling of cumulative production results in a specified percentage reduction in costs. It is a function of the “progress rate” which represents the portion of costs that remain after each step of learning. The reduction percentage is called "learning rate" which is equal to 1 minus the progress rate. Learning can be generally noted as follows:

$P(n) = a * n^{-b}$, where .

Where, $P(n)$ = the cost for the n_{th} unit,

n = cumulative number of units produced,

a and b are constants.

Since $P(1) = a$, a represents the cost of the first unit. $P(2n) = a\,(2n)^{-b} = 2^{-b}a*n^{-b} = 2^{-b} * P(n)$. Therefore, the cost per unit falls to 2^{-b} percent of the previous per unit cost as the cumulative output doubles. The number 2^{-b} is the progress rate representing the portion of costs remained after doubling the cumulative production and $1 - 2^{-b}$ is the learning rate representing the reduction percentage for that progress rate.[113] For example, if b =0.322, then 2^{-b} = 80% and $1 - 2^{-b}$ = 20%. This curve referred to as the "80 percent curve" shows that the average unit price became 80 percent of the previous unit price (i.e., 20% reduction) when cumulative production doubled. The learning curve is also referred as the log-linear model since its log format is linear as shown below:

$$\ln(P(n)] = \ln(a * n^{-b})$$
$$\ln[P(n)] = \ln(a) + \ln(n^{-b})$$
$$\ln[P(n)] = \ln(a) - b*\ln(n)$$

where, ln is the log function.

With the learning curve, we can estimate the progress rate for a certain cumulative output volume relative to the unit cost of a base production volume. The base production volume in this analysis is the number of vehicles that will have the V2V technology in the first year (i.e., 2021) and the unit costs for 2021 were those estimated in Table VII-4. Linking the cumulative production units with the time (i.e., year), the progress rate for year i (annual progress rate) can be note as:

[113] Dutton, Thomas, and Butler (1984) call −b the progress rate; Dutton, John M, and Thomas, Annie Treating Progress Functions as a Managerial Opportunity", Academy of Management Review, 1984, Vol. 9, No. 2, pp.235-247

$$PR_i = \frac{P(n_i)}{p(n_0)} = \frac{a^*n^{-b}}{a^*n_0^{-b}} = (\frac{n_i}{n_0})^{-b} = (\frac{n_0}{n_i})^b$$

Where, PR_i = annual progress rate (i.e., the portion of cost remained) to the 2021 base cost

n_0 = the number of MY 2021 vehicles that would have the V2V technology, $n_0 > 0$.

n_i = the cumulative number of vehicles that would have the V2V technology at year i.

The unit cost at the cumulative volume n_i (or year i) thus is equal to a * PR_i.

As discussion above, progress rate is critical for establishing an appropriate learning curve. If the progress rate (i.e., 2^{-b}) is established, then the b above can be determined as -ln(progress rate)/ln(2). To establish the progress rate of a product, the history of its direct costs and the corresponding production cumulative volume are required. The progress rate most often cited in the literature, 80%, is a general average derived from Dutton and Thomas' 1984 compilation of over 100 empirical studies of progress curves in a large variety of industries between 1920 and 1980[114]. However, as those authors are careful to point out, the average progress rate across all of these studies has not been found to be a good predictor for specific industries. Baloff too warns against use of this simple average curve.[115] For example, Table VII-5 provides the progress rates for a variety of technologies gathered from more recent studies. The progress rates ranged from 77 percent to 97 percent with an average closer to 90% than 80%.

[114] Dutton op.cit.

[115] Baloff, Nicholas, Extension of the Learning Curve – Some Empirical Results, Operational Research Quarterly (1970-0971), Vol 22, No. 4 (Dec., 1971, pp.32-43.

Table VII-5
Progress Rates and Learning Rates for Selected Technologies

Technology	Progress Rate	Learning Rate*
Solar Power[116]	0.77	0.23
Wind Power[117]	0.87	0.13
Ethanol[118]	0.85	0.15
PV Inverters[119]	0.94	0.06
Solar Thermal[120]	0.97	0.03
Flue Gas DeSOx[121]	0.89	0.11
Flue Gas DeNOx[122]	0.88	0.12

*= 1 – progress rate

However none of the technologies shown in Table VII-5 are produced within the light vehicle industry or in volumes similar to those produced in that industry (although PV inverters require electronics technology similar to that used in some automotive applications). Their progress rate might not be applicable to V2V. To address this concern, the agency examined the cost and production changes for several vehicle technologies to produce a sample of these rates specifically for the light vehicle industry. NHTSA routinely performs evaluations of the costs and benefits of safety standards that were previously issued. To estimate costs, the agency conducts a teardown study of the technologies used to meet the standards. In some cases, the agency has performed multiple evaluations over a span of years. For example, a teardown study may be performed to support the agency's initial estimates of costs that will result from the regulation, and again five years later to evaluate the impacts of the regulation after it has been in

[116] The Carbon Productivity Challenge: Curbing Climate Change and Sustaining Economic Growth, McKinsey Climate Change Special Initiative, McKinsey Global Institute, June 2008 (quoting from UC Berkeley Energy Resource Group, Navigant Consulting)

[117] Ibid

[118] Spinney, Bruce C., Faigin, Barbara M., Bowie, Noble N., Kratzke, Stephen R., "Advanced Air Bag Systems Cost, Weight, and Lead Time Analysis Summary Report, Contract No. DTNH22-96-0-12003", NHTSA, p.3.18

[119] Ibid

[120] Ibid

[121] Technology Innovation for Climate Mitigation and its Relation to Government Policies, Edward S. Rubin, Carnegie Mellon University, Presentation to the UNFCCC Workshop on Climate Change Mitigation, Bonn, Germany, June 19, 2004

[122] Ibid

effect. These data, together with actual production data, supply the necessary information that was required to develop a learning curve for the technology.

The technologies that were examined were air bags, antilock braking systems, 3-point manual outboard safety belts with retractors, dual master brake cylinders, and adjustable head restraints. Table VII-6 summaries the derived progress rates which range from 0.90 for antilock brakes to 0.96 for 3-point belts with retractors. The average progress rate for these five technologies is 0.93 (i.e., 2^{-b}) which was used to estimate the reduction in price that would result from learning associated with gradual increases in cumulative production of V2V systems. This rate will also be assumed to apply to apps.

Table VII-6

Progress Rates and Learning Rates for Automotive Safety Technologies

Technology	Progress Rate	Learning Rate*
Driver Air Bags	0.93	0.07
Antilock Braking Systems	0.90	0.10
Manual Lap/Shoulder Belts	0.96	0.04
Adjustable Head Restraints	0.91	0.09
Dual Master Brake Cylinders	0.95	0.05
Average	0.93	0.07

*= 1 – progress rate

The progress rates from these five safety related technologies in light vehicles are roughly .10 to .15 higher than the all-industry average noted in Dutton and Thomas and others. This implies that the price reduction percentage (i.e., learning rate) for V2V will be smaller than the Dutton's all-industry average.

Using the progress rate of 93 percent when doubling the cumulative production, we can determine b in the above formula for annual progress rates (i.e., PR_i) is 0.1047 [= ln(0.93)/ln(2)]. With the value of b and the V2V vehicle volume, we can estimate the annual progress rates. Table VII-7 shows these rates for DSRC radios and apps. Applied these rates to the year 1 component unit costs derives the projected component unit costs after learning. DSRC radios and apps have a separate annual progress rate since they have different production volumes.

Based on our technology adoption scenario, the apps production is slower and volume is smaller than the DSRC radios for the first few years.

As shown, the unit price for two ratios including apps is about $350.57 in 2021. Due to learning, the unit price would be progressively lower to $218.85 in 2060, about 62.5 percent of the price estimated in 2021. With the same learning pattern, the cost of one radio is estimated to be $249.18 in 2021 and the unit price would gradually reduce to $155.47 in 2060.

Table VII-7
Annual Progress Rates and Component Unit Costs After Learning
(2014 $)

	Calendar	Progress Rates		Unit Costs			Total Unit Costs	
Year	Year	Radio	Apps	1 Radio	2 Radio	Apps	1 Radio	2 Radios
1	2021	1.000	1.000	$247.18	$348.57	$2.00	$249.18	$350.57
2	2022	0.908	1.000	$224.44	$316.50	$2.00	$226.44	$318.50
3	2023	0.853	0.872	$210.95	$297.47	$1.74	$212.69	$299.22
4	2024	0.821	0.782	$202.91	$286.14	$1.56	$204.47	$287.70
5	2025	0.798	0.726	$197.21	$278.10	$1.45	$198.66	$279.56
6	2026	0.780	0.681	$192.83	$271.93	$1.36	$194.19	$273.29
7	2027	0.766	0.647	$189.27	$266.91	$1.29	$190.57	$268.21
8	2028	0.754	0.623	$186.28	$262.69	$1.25	$187.53	$263.94
9	2029	0.743	0.606	$183.71	$259.07	$1.21	$184.92	$260.28
10	2030	0.734	0.593	$181.45	$255.88	$1.19	$182.63	$257.06
11	2031	0.726	0.582	$179.44	$253.04	$1.16	$180.60	$254.20
12	2032	0.719	0.573	$177.62	$250.48	$1.15	$178.77	$251.63
13	2033	0.712	0.565	$175.98	$248.16	$1.13	$177.11	$249.29
14	2034	0.706	0.558	$174.47	$246.03	$1.12	$175.58	$247.15
15	2035	0.700	0.552	$173.07	$244.06	$1.10	$174.17	$245.17
16	2036	0.695	0.546	$171.77	$242.23	$1.09	$172.87	$243.32
17	2037	0.690	0.541	$170.56	$240.52	$1.08	$171.64	$241.60
18	2038	0.685	0.537	$169.42	$238.92	$1.07	$170.49	$239.99
19	2039	0.681	0.532	$168.35	$237.40	$1.06	$169.41	$238.47
20	2040	0.677	0.528	$167.33	$235.97	$1.06	$168.39	$237.03
21	2041	0.673	0.525	$166.37	$234.61	$1.05	$167.42	$235.66
22	2042	0.669	0.521	$165.48	$233.36	$1.04	$166.52	$234.40
23	2043	0.666	0.518	$164.64	$232.17	$1.04	$165.68	$233.21
24	2044	0.663	0.515	$163.84	$231.04	$1.03	$164.87	$232.07
25	2045	0.660	0.512	$163.07	$229.96	$1.02	$164.09	$230.98
26	2046	0.657	0.509	$162.33	$228.92	$1.02	$163.35	$229.94
27	2047	0.654	0.507	$161.63	$227.93	$1.01	$162.64	$228.94
28	2048	0.651	0.504	$160.95	$226.97	$1.01	$161.96	$227.98
29	2049	0.649	0.502	$160.30	$226.05	$1.00	$161.30	$227.05
30	2050	0.646	0.500	$159.67	$225.16	$1.00	$160.67	$226.16
31	2051	0.644	0.498	$159.07	$224.31	$1.00	$160.06	$225.31

32	2052	0.641	0.496	$158.48	$223.49	$0.99	$159.48	$224.48
33	2053	0.639	0.494	$157.93	$222.70	$0.99	$158.91	$223.69
34	2054	0.637	0.492	$157.39	$221.94	$0.98	$158.37	$222.93
35	2055	0.635	0.490	$156.87	$221.21	$0.98	$157.85	$222.19
36	2056	0.633	0.488	$156.36	$220.50	$0.98	$157.34	$221.48
37	2057	0.631	0.486	$155.88	$219.82	$0.97	$156.85	$220.79
38	2058	0.629	0.485	$155.41	$219.15	$0.97	$156.38	$220.12
39	2059	0.627	0.483	$154.95	$218.51	$0.97	$155.92	$219.48
40	2060	0.625	0.482	$154.51	$217.89	$0.96	$155.47	$218.85

Table VII-8 summarizes the total annual vehicle component costs. As shown, the vehicle component costs would range from $2.0 billion to $4.9 billion. The cost per vehicle would range from $123.59 to $297.65. The lower bound is for one radio at year 2021 and the higher bound is the cost for two radios in 2023. In 2023, 100 percent of vehicles would be required to be equipped with the DSRC radios and more vehicles would be expected to have apps. Although the projected number of new vehicles that would have DSRC radios and apps still increase after 2023, the additional costs would be absorbed by the falling component price based on the learning effect. Note that the cost per vehicle is the average cost for all <u>new</u> vehicles instead of for affected vehicle. Therefore, the cost per vehicle for these two years was significantly lower than the unit cost shown in Table VII-7. Furthermore, the full apps deployment would not be achieved until 2028. As a result, the cost per vehicle for 2023 to 2027 was slighter lower than that shown in Table VII-7.

Table VII-8
Total Annual Vehicle Component Costs
(2014 $ and Vehicles in Millions)

Year	Calendar Year	Vehicles With		Total Costs (Radios + Apps)		Cost Per Vehicle	
		Radios	Apps	1 Radio	2 Radios	1 Radio	2 Radios
1	2021	8.10	0.00	$2,000.92	$2,821.67	$123.59	$174.29
2	2022	12.26	0.61	$2,751.72	$3,879.94	$168.40	$237.45
3	2023	16.44	1.64	$3,470.84	$4,893.35	$211.12	$297.65
4	2024	16.53	4.13	$3,360.54	$4,736.34	$203.30	$286.53
5	2025	16.67	6.67	$3,297.19	$4,645.68	$197.79	$278.68
6	2026	16.75	10.89	$3,244.74	$4,569.60	$193.72	$272.81
7	2027	16.88	15.19	$3,214.60	$4,525.12	$190.44	$268.08
8	2028	17.03	17.03	$3,193.60	$4,494.87	$187.53	$263.94
9	2029	17.13	17.13	$3,167.72	$4,458.56	$184.92	$260.28
10	2030	17.30	17.30	$3,159.58	$4,447.19	$182.63	$257.06
11	2031	17.44	17.44	$3,149.66	$4,433.29	$180.60	$254.20
12	2032	17.56	17.56	$3,139.20	$4,418.61	$178.77	$251.63

13	2033	17.67	17.67	$3,129.51	$4,405.01	$177.11	$249.29
14	2034	17.84	17.84	$3,132.41	$4,409.12	$175.58	$247.15
15	2035	18.00	18.00	$3,135.14	$4,412.99	$174.17	$245.17
16	2036	18.16	18.16	$3,139.24	$4,418.78	$172.87	$243.32
17	2037	18.34	18.34	$3,147.91	$4,431.00	$171.64	$241.60
18	2038	18.49	18.49	$3,152.45	$4,437.40	$170.49	$239.99
19	2039	18.66	18.66	$3,161.27	$4,449.84	$169.41	$238.47
20	2040	18.87	18.87	$3,177.54	$4,472.75	$168.39	$237.03
21	2041	19.14	19.14	$3,204.34	$4,510.49	$167.42	$235.66
22	2042	18.56	18.56	$3,090.70	$4,350.52	$166.52	$234.40
23	2043	18.66	18.66	$3,091.52	$4,351.69	$165.68	$233.21
24	2044	18.76	18.76	$3,092.91	$4,353.66	$164.87	$232.07
25	2045	18.87	18.87	$3,096.45	$4,358.65	$164.09	$230.98
26	2046	18.97	18.97	$3,098.81	$4,361.98	$163.35	$229.94
27	2047	19.08	19.08	$3,103.22	$4,368.19	$162.64	$228.94
28	2048	19.18	19.18	$3,106.39	$4,372.65	$161.96	$227.98
29	2049	19.28	19.28	$3,109.91	$4,377.61	$161.30	$227.05
30	2050	19.39	19.39	$3,115.37	$4,385.30	$160.67	$226.16
31	2051	19.39	19.39	$3,103.57	$4,368.70	$160.06	$225.31
32	2052	19.39	19.39	$3,092.23	$4,352.74	$159.48	$224.48
33	2053	19.39	19.39	$3,081.32	$4,337.38	$158.91	$223.69
34	2054	19.39	19.39	$3,070.79	$4,322.57	$158.37	$222.93
35	2055	19.39	19.39	$3,060.63	$4,308.27	$157.85	$222.19
36	2056	19.39	19.39	$3,050.82	$4,294.46	$157.34	$221.48
37	2057	19.39	19.39	$3,041.33	$4,281.11	$156.85	$220.79
38	2058	19.39	19.39	$3,032.14	$4,268.17	$156.38	$220.12
39	2059	19.39	19.39	$3,023.24	$4,255.64	$155.92	$219.48
40	2060	19.39	19.39	$3,014.60	$4,243.49	$155.47	$218.85

B. Communication Costs

The communication cost estimates were based on the model created by Booz Allen Hamilton under the contract with the DOT's Intelligent Transportation Systems Joint Program. The model, Cost Model for Communications Data Delivery System (CDDS), is a Microsoft Excel-based model.[123] BAH also provided DOT the report titled "Communications Data Delivery System Analysis for Connected Vehicles: Revision and Update to Modeling of Promising Network Options."[124] This report detailed the SCMS functional and security assumptions and sources for

[123] Docket No. NHTSA-2014-0022

[124] BAH CDDS Final Report. See Docket No. NHTSA-2014-0022

input values to the CDDS model. This PRIA used the cases that we feel are most reasonable for estimating the communication cost.

The CDDS model was created based on the assumption that a PKI system will be used in order to meet the agency's security needs. As part of PKI, each vehicle is given a set of digital certificates. These anonymous certificates were assumed to last for only 5 minutes, so even if someone wanted to track a device by its certificate with sophisticated and expensive equipment, it would be even more difficult to do so for longer than 5 minutes, when the vehicle starts using a completely different certificate. This makes the system harder to break into and makes it very hard to track vehicles.

Furthermore, under the current security model,[125] all vehicles would be sent a list of "misbehaving" certificates that they could encounter. While the approach to misbehavior has not been decided, one method could be that any time bad V2V information is sent, due to an error or due to intentional human tampering, the certificate tied to that bad V2V data would be recorded and later uploaded when the vehicle transmits data to the SCMS. This way, the SCMS that handles the certificates knows that a vehicle carrying a certain batch of certificates is misbehaving, and is able to put together a list of all the certificates that a misbehaving vehicle currently has available. Then, when vehicles connect to the system, they will be warned about certain certificates to avoid trusting. That list is called the Certificate Revocation List (CRL).

Therefore, based on the security system design used in the PRIA, communications between vehicles and the SCMS include the following activities.

- UPLOAD - a request for new certificates
- DOWNLOAD - new certificates
- UPLOAD – reporting misbehavior
- DOWNLOAD – a full or partial CRL and

[125] NHTSA plans to continue researching security options, including those that may be significantly less costly due to decreased reliance on burdensome distribution of CRLs.

- conduct other data functions or system updates

The next several paragraphs detail the cost factors for these communication activities. The cost factors include the new certificate deployment, misbehavior detection and CRL distribution strategy, and the communication systems that would be used to support these activities.

B.1 New Certificates

The CDDS model used a two-phased new certificate deployment strategy that CAMP was developed: the "initial deployment" and "full deployment." The initial deployment refers to the first three years of SCMS implementation. During the three years of initial deployment stage, communications between devices and SCMS will not be generally available[126] because the communication network will not be established. Batches of certificates for a three-year use are required to be downloaded for new vehicles that are produced in this stage. These batches would include reusable, overlapping five-minute certificates valid for one week. The term "overlapping" in this context refers to the fact that any certificate can be used at any time during the validity period. The batches would be good for one week and at this point are assumed to be around 20 certificates per week, which equates to 1,040 for one year of certificates. As the frequency of the certificate download batch changes for full deployment, the number and therefore size of the certificate batches also changes accordingly.[127]

Certificate Updates – the download frequency of certificates at full deployment will impact the costs of updates. BAH considered two download sizes. One size is 3,000 certificates for any frequency of download and the other one is 6,000 certificates with a three-year download. BAH also considered 2-year downloads.

[126] BAH CDDS Final Report, at 22 at Docket No. NHTSA-2014-0022

[127] BAH CDDS Final Report at 15 at Docket No. NHTSA-2014-0022

B.2 Misbehavior

Detection and Reporting

The BAH model assumed that the device would perform a plausibility check on incoming messages. If the message is deemed implausible, the device would report that certificate number as misbehaving. This report would then be checked by the Misbehavior Authority of the SCMS, which would revoke the misbehaving vehicle's certificates (not by identifying the vehicle, but by identifying the batch of certificates that the misbehaving certificate came from) if the report was deemed to be accurate. The CRL is a list created by the SCMS that identifies certificate numbers that are sending out messages that are misbehaving. These vehicles could be sending out messages that erroneously alert drivers of other vehicles, either intentionally or from misbehaving sensors. BAH has outlined several ways by which vehicles may be added to the CRL, as presented below.[128]

- Administrative revocation, which would be based on a pre-determined set of criteria, not based on actual misbehavior. For example, vehicles that are formally retired, or otherwise determined to be removed from the system for non-misbehaving reasons, could make up entries on the CRL.
- Vehicles that observe other vehicles distributing obviously erroneous messages report those vehicles. These observations would be based on plausibility checks that would verify if the message content made physical sense.
- All vehicles report any received message that results in a positive application action (i.e., any message that provides an alert to the driver and a commensurate action). For example, if an in-vehicle application issued a warning to the driver based on a received message, that message would be sent to the Misbehavior Authority (MA). This approach would identify as misbehaving vehicles that were emitting messages that passed plausibility checks but were potentially erroneous to the extent that they were causing a large number of warnings.
- Vehicles randomly select received messages to send to the MA, and the MA would seek

[128] BAH CDDS Final Report at 47 at Docket No. NHTSA-2014-0022

to identify trends and patterns from the randomly sampled messages.[129]

It is also possible that a vehicle could self-report if it determines that it is not operating properly, and this might also result in a revocation.

BAH has outlined several problems that could arise as a result of misbehaving messages. If a message is received from a certificate number that is on the CRL, that message is ignored. However, if it is not on the CRL, the message would need to be checked for misbehavior. BAH has outlined the responses to these scenarios.[130]

- The result of receiving a message from a legitimate, non-misbehaving certificate number will depend on the vehicle situation.
    - If the data in the message indicates a danger, then the vehicle warning system will take positive action (warn the driver).
    - If the data in the message indicates no danger, then the system will take no action (no warning will be issued)

- The result of receiving a message from a misbehaving certificate number that is not on the CRL and which passes the plausibility tests will also depend on the vehicle situation.
    - If the data in the message indicates a danger, then the system will take positive action (warn the driver).
    - If the data in the message indicates no danger, then the system will take no action (no warning will be issued).

Attacks on the CRL have been considered by BAH. The BAH CDDS final report recognizes four types of attackers.[333]

- A1 (Clever Outsider): A talented engineer and/or cryptographer who does not possess any inside knowledge.

[129] Unless the sampling rate is high, the overall effectiveness of this approach is uncertain. If the misbehavior rate is1% (maximum assumed level), and the sample rate is 1%, the n this approach will, on average, detect 0.01% of the misbehaving vehicles, assuming the detection process is 100 percent effective. If the sample rate is higher, the n the sampling process will represent a greater data load than the CRL.
[130] BAH CDDS Final Report at 49 at Docket No. NHTSA-2014-0022

- A2 (Knowledgeable Insider): An insider who possesses detailed knowledge about the system (security and non-security related) and has access to its specifications.
- A3 (Funded Organizations): An organization that has access to substantial resources and furthermore possesses the capabilities of attacker A2.
- A4 (Certificate Authority insider): An insider who possesses detailed knowledge about the system and has access to confidential information at the CA level. A4 is an insider at the CA and as such compromises the root of trust of the V2V communication system.
  - Because it is the CA's responsibility to guard against such an attacker, A4 is considered out of scope.

Finally, BAH referenced a DOT report that identified two primary security risks:[131]

- **Attacks on the user/risks to safety and user acceptance:** these attacks are aimed at users and directly impact user safety and indirectly impact system acceptance.
- **Attacks on the communications system/risks to privacy:** these attacks could either (1) track the location and driving routes of a person; (2) cause a vehicle to be falsely reported for misbehavior, causing a valid driver to be removed from the system.

Other types of attacks, such as cyber-attacks across the entire vehicle fleet, have been considered but not yet addressed. These attacks will be addressed at a later date.

Certificate Revocation and Certificate Revocation List

The revocation process has not yet been finalized. The BAH analysis assumed that any devices that are misbehaving would be added to the CRL, which would be sent to the OBE at BAH considered misbehavior rates at three levels: 1 percent, 0.5 percent, and 0.1 percent. There is no way to accurately predict the misbehavior rate. The capabilities of the system to deliver the required amount of data to vehicles on a daily basis can be influenced by a change in the misbehavior rate and its influence on the size of the CRL. In a heavy data-

[131] *An Approach to Communications Security for a Communications Data Delivery System for V2V/V2I Safety: Technical Description and Identification of Policy and Institutional Issues* (FHWA, Nov. 2011) at http://ntl.bts.gov/lib/43000/43500/43513/FHWA-JPO-11-130_FINAL_Comm_Security_Approach_11_07_11.pdf (last accessed Jan. 29, 2014).

requirement scenario (1 percent annual revocation rate, 3 year certificate lifetime, CRL updated daily), the BAH analysis estimated that the system would need to be able to deliver 150 MB of data to each vehicle every day. This could lead to a significant difference in costs if using commercial services such as cellular instead of DSRC. Because of the potential of significant cost increases due to data volume, BAH considered three ways to reduce CRL distribution communication load.

- Balance certificate lifetime with CRL size. When certificates expire, there is no need for them to be retained on the CRL. As a result, reducing the lifespan of certificates would also reduce the size of the CRL.
- Eliminate redundancy in the distributed CRL. If a vehicle can observe and report its own misbehavior, it would be able to stop transmitting messages and would be ignored by other vehicles without needing to check the CRL.
- Incremental CRL updates. Theoretically, a vehicle would only need to download the changes to the CRL since its last update, rather than the entire CRL each time. A vehicle driven every day would only have to receive a single day's worth of updates. However, if a car has not been driven in a longer period of time, the update will be larger, and will be susceptible to receiving bad messages until it is fully updated, though the small size of the updates would likely mean that these vehicles could be updated quickly.

Internal Blacklist – This would be used by the SCMS to make sure that an OBE asking for new certificates is not on the revoked list. If a vehicle or device is on the list, no certificate updates will be issued.

B.3 Communication Systems

Communication costs include the cost of in-vehicle communication components and any service fee that came with the communication network.   For system design, the BAH considered four communication network technologies: cellular, Wi-Fi, Satellite, and DSRC for the CDDS. The four technologies can be combined in various ways to form the communication system to support the vehicle to SCMS communication activities described previously. After the publication of ANPRM and the Request for Comments (RFC) on SCMS, the agency has met with several commenters on SCMS and gained more knowledge on cellular and satellite and how these technologies can support the communication between vehicles and SCMS.[132] Based on what we had learned, the agency concludes that two systems can meet the proposed security requirements:

- **Hybrid.** This system would use cellular, Wi-Fi, and satellite for vehicles to SCMS communication.
- **DSRC.** This protocol would use DSRC exclusively for V2V communications and for vehicles to SCMS communications through Roadside Equipment (RSE).

The hybrid system contains all three technologies since each has its weakness and strength. Cellular systems are very common throughout the nation and are continuing to expand. In particular, the advancement of LTE (long-term evolution) technology is helping to deliver larger amounts of data to cellular users more quickly. However, BAH stated that this is less effective when a user is moving, and that the data rate for LTE is often much lower than what is theoretically possible. Although LTE would be able to support the full download of CRL due to the expansiveness of cellular networks, there are areas where cellular networks are not available, and coverage can experience dead spots at times. Another issue that may arise is the fact that any LTE system may suffer from capacity issues in any area that has many LTE users. Though cellular could potentially be a viable option for coverage.

Wi-Fi technology supports wireless connectivity and generally higher data rates. The main drawback of Wi-Fi is its design for stationary terminals. Though Wi-Fi offers higher data rates than other options, it does not work nearly as well with moving terminals. In addition, any vehicle that enters the Wi-Fi hotspot must give its MAC (media access control) address and obtain the MAC address of all other vehicles in the hotspot before it can send communications. Though it uses the same basic radio system as DSRC, DSRC eliminates

[132] Docket No. NHTSA-2014-0023

the need for users to gather MAC addresses before communication. In general, this means that Wi-Fi cannot support data exchanges with vehicles moving at road speeds.

Satellite radio, or Satellite Digital Audio Radio Service (SDARS), uses satellites to provide digital data broadcast service. SiriusXM claims the following coverage capability.[133]

- 3,717,792 mi^2 (9,629,044 km^2) of "seamless" nationwide coverage (approximately
- 98% of the U. S. land mass)
- 200 miles (322 km) off-shore coverage
- Comparison with terrestrial radio coverage of 50-100 miles (80-160 km)

However, BAH suggested that SDARS could not support the download of a full CRL because the download time would be longer than the average trip. If an incremental system is used, however, it could support updates. The costs and security risks associated with cellular also apply to satellite.

Due to the concerns with each of the technologies and to ensure seamless operation, the hybrid we examined is the combination of these three technologies. Each serves as a complement system as the other. As for security concern, the agency added the cost of in-vehicle HSM based on our conversations with security experts who believe HSM can address over-the -air communication security issues. Furthermore, the satellite communication will not be as expensive as BAH' estimates when taking into account that 70 percent of light vehicles already had satellite radios. Since only 30 percent of vehicles need satellite radio, the component cost for satellite communication is greatly reduced. Finally, the agency believes that an incremental CRL is feasible and the satellite is adequate for this CRL distribution.

The DSRC-exclusive system would communication with SCMS through RSEs. RSEs are small base stations that would be need to set up to allow the vehicles to "phone home" using DSRC. In order to make sure that the V2V system can constantly be listening for safety component update related communications, a separate DSRC antenna will be used

[133] SiriusXM Web site. See www.siriusxm.com/whatissiriusxm (last accessed Jan. 29, 2014).

exclusively for communicating update. In addition, a separate DSRC and antennae will be needed for communication when vehicles talk to other vehicles and send the basic safety message. Therefore, two DSRC radios would be required for this DSRC-exclusive communication system.

In order to determine how many RSE would appear to be optimal for DSRC communications, Deployment of RSEs was considered on three different types of roads: secondary roads, interstate highways, and National Highway System roads (NHS). Each type is defined by BAH as the following:[134]

- Secondary roads refer to collector roads, State highways, and county highways that connect smaller towns, subdivisions, and neighborhoods.
- Interstate highways are the network of freeways that make up Dwight D. Eisenhower National System of Interstate and Defense Highways.
- The NHS roads are the collection of interstate highways, principal arteries, strategic highways, major network connectors, and intermodal connectors.

BAH used spatial optimization and information from the 2009 National Household Transportation Survey (NHTS) to estimate the required number of RSE to achieve the desired amount of coverage. The usage of NHS roads (with 19,749 sites) was deemed the most logical because it achieves greater coverage than the interstate option (with 8,880 sites) while also requiring fewer RSE than secondary roads (with 149,434 sites) to achieve the same coverage, as shown below in Figure VII-1. As shown, NHS roads are the most realistic scenario, though secondary roads could achieve more coverage given more resources. Ultimately, the NHS road deployment method was deemed to be the most realistic.

[134] BAH CDDS Final Report, at 27. See Docket No. NHTSA-2014-0022

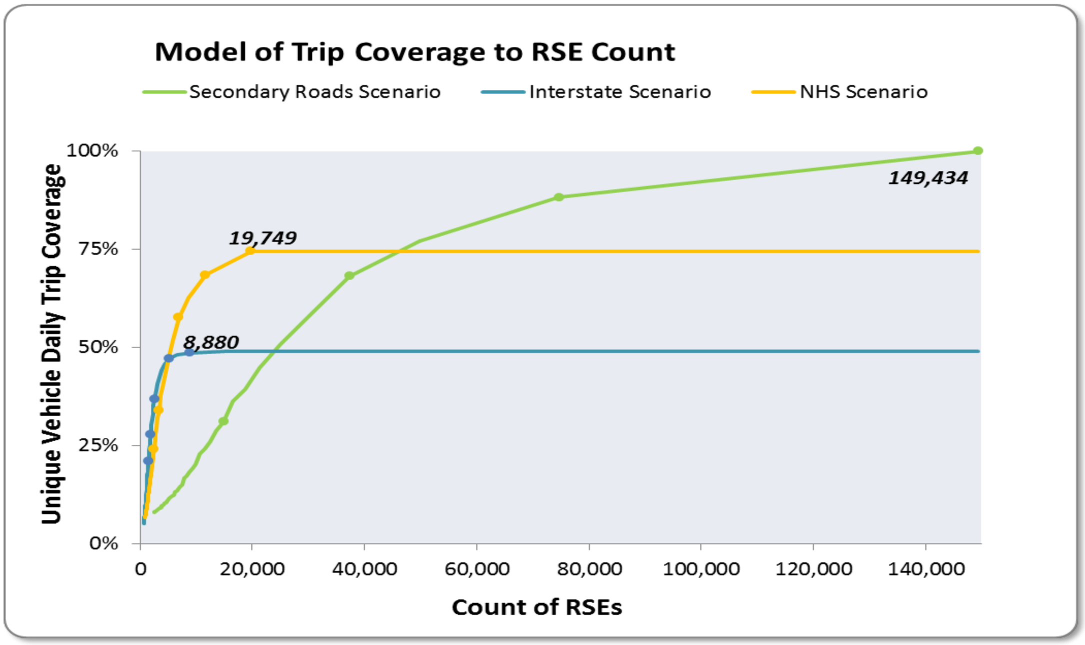

Figure VII-1 Coverage of RSE by Road Type

B.4 Cost estimates

The PRIA used the assumptions that were used in the CDDS model to estimate the communication costs. These assumptions included the length of initial new certificate deployment period, the certificate download size and frequency at the full deployment stage, misbehavior rate, and the size of CRL (i.e., CRL type). In addition, for the Hybrid option, the cost model also considered the costs that relate to the three communication technologies: cellular data rate, cellular component cost in the vehicles, Wi-Fi component costs, satellite data rate, and satellite radio. For the DSRC-exclusion system, the cost model would consider the cost of RSE. Both communications would require DSRC spectrum since it is required for transmitting safety messages among vehicles. For the DSRC option, one channel would be designated for safety (Channel 172) and another would be for the communication between vehicles and SCMS. This channel also can be used for V2I. For the hybrid option, although only requiring one channel, it might also need to reserve the spectrum for V2I applications. In the NPRM, we seek input on which channel would be best to handle this communication traffic. Unless otherwise stated, all cost calculations have been made with the assumptions from Table VII-9. The costs were estimated for 40 years.

Of the assumptions, the costs of an OBE for cellular are estimated at $10, the cost for Wi-Fi is estimated at $2 per vehicle, and the OBE costs for a satellite system are estimated at $20. However, currently about 70 percent of the light vehicles already have satellite radios. After factoring the take rate, the OBE costs per vehicle would be $6.00 (= $20 * 0.3). The total OBE costs for the Hybrid option thus are $18 per vehicle (= $10 + $2 + $6) to cover cellular, Wi-Fi, and Satellite. There is no estimated OBE cost for the DSRC option since the cost of the required equipment for DSRC radios was already included in the in-vehicle component costs previously estimated. However, for the DSRC option, RSE is the only cost factor. There are two major costs for RSE: RSE structure supporting costs and replacement costs. The RSE structure support is estimated to be $8,839 per RSE. This cost included equipment cabinet that houses the RSE, the labor to install the cabinet, power line installation to the cabinet, structure drawing, and permit costs. The replacement cost is estimated to be $22,719 per RSE. The replacement costs included the RSE unit, RSE enclosure, power supplier device and connection, communication system, and wiring. We did not apply learning to these costs since the total units would be needed is relative low to show the impact of learning. The total RSE that would be needed is about 19,750 units at full deployment which would be achieved at year 16 (i.e., 2036).

Aside from added costs, the OBE components will add additional weight to the vehicles. The additional weight of cellular, Wi-Fi, and satellite OBE components is estimated to be 0.15 pounds per vehicle after factoring the 70 percent take rate. The estimated weight basically came from the satellite radio which is estimated to be 0.5 pounds per unit.[135] This weight will combine with those estimated in the vehicle component section to estimate the fuel impacts of these additional weights.

[135] Based on the confidential discussion with a satellite service/supplier company

Table VII-9
Cost Assumptions by Communication Options

Cost Factors	Component	Hybrid	DSRC
Certificate			
	Certificate Option	3000 per bundle	3000 per bundle
	Certificate Phase-In Period	3 years	3 years
	Certificate Download Frequency at Full Deployment	Every 3 years	Every 3 years
Misbehavior			
	Misbehavior Rate	0.10%	0.10%
	CRL Type	Satellite/Incremental	Incremental
Communication Technology			
Cellular	Cellular Data Price	$4.00 / GB	NA
	Cellular Component Cost Per Vehicle	$10.00	NA
	Fraction of Data Shifted from Cellular	67%	NA
Wi-Fi	Wi-Fi Component Cost per Vehicle	$2.00	NA
Satellite	Satellite Data Price	$1.60 /GB	NA
	Satellite Component Cost per Vehicle	$6.00	NA
Three Above Combined	Annual Technology Component Replacement Rate	2%	NA
RSE	RSE Component per Vehicle	NA	Included in the DSRC radios
	# Nationwide RSEs	NA	19,750
	RSE Structure Supporting Cost	NA	$8,839
	RSE Replacement Cost	NA	$22,719
	RSE Installation Phase-in	16 Year	NA
	RSE Life	NA	15 years

B.3.1 The Hybrid Option

This option uses cellular and satellite technologies and opportunistic use of Wi-Fi. CRL would be broadcast through satellite. Since the certificate phase-in is three years, the communication between vehicles and SCMS were very limited. In these first three years the costs primarily were from the OBE and the replacement costs. Data costs for both cellular and satellite would start to kick in the fourth year. Table VII-10 summarizes the estimated annual communication costs for the Hybrid system. The annual overall costs for the Hybrid communication option would range from approximately $148.6 million in Year

1 to approximately $493.9 million at Year 40. On a per vehicle basis, this equates to $9.18 in Year 1 to $25.47 after 40 years. The cost increase over time reflects the increases in certificate registration and distributions and SCMS communications as fleet penetration increases. Note that the zero data costs in the first three years are due to the assumption that vehicles will be pre-loaded with three years of security certificates for the first three years. Because a very small portion of vehicles will be equipped with DSRC and these vehicles will be spread out across the U.S., communication between vehicles and SCMS is expected to be very limited during this time period. Therefore, we believe that the data transmitting is not necessary during the first three years.

Table VII-10
Estimated Annual Communication Costs and Per Vehicle Costs
Hybrid (2014 $)

Year	Calendar Year	RSE	OBE	Data Cost Satellite	Data Cost Cellular	Total	Cost Per Vehicle
1	2021	$0	$148,624,200	$0	$0	$148,624,200	$9.18
2	2022	$0	$213,159,926	$0	$0	$213,159,926	$13.05
3	2023	$0	$309,000,919	$0	$0	$309,000,919	$18.80
4	2024	$0	$316,361,705	$14,502	$5,964,604	$322,340,811	$19.50
5	2025	$0	$324,585,446	$20,225	$7,771,778	$332,377,450	$19.94
6	2026	$0	$331,663,749	$26,516	$9,558,220	$341,248,485	$20.37
7	2027	$0	$339,583,781	$33,316	$11,326,199	$350,943,297	$20.79
8	2028	$0	$347,798,557	$41,044	$13,073,502	$360,913,103	$21.19
9	2029	$0	$355,008,739	$49,204	$14,787,665	$369,845,609	$21.59
10	2030	$0	$363,357,905	$57,691	$16,463,486	$379,879,082	$21.96
11	2031	$0	$370,982,194	$66,319	$18,080,731	$389,129,243	$22.31
12	2032	$0	$378,019,671	$74,932	$19,626,112	$397,720,714	$22.65
13	2033	$0	$384,620,645	$83,389	$21,090,223	$405,794,257	$22.97
14	2034	$0	$392,045,404	$91,615	$22,473,154	$414,610,174	$23.24
15	2035	$0	$399,021,900	$99,529	$23,771,089	$422,892,517	$23.49
16	2036	$0	$405,714,525	$107,044	$24,979,082	$430,800,651	$23.72
17	2037	$0	$412,479,551	$114,107	$26,095,952	$438,689,610	$23.92
18	2038	$0	$418,390,535	$120,627	$27,113,321	$445,624,483	$24.10
19	2039	$0	$424,344,445	$126,553	$28,030,229	$452,501,226	$24.25
20	2040	$0	$430,726,546	$131,916	$28,854,679	$459,713,141	$24.36
21	2041	$0	$437,935,982	$136,760	$29,599,075	$467,671,817	$24.43
22	2042	$0	$429,324,211	$140,688	$30,178,332	$459,643,231	$24.77
23	2043	$0	$432,732,888	$144,189	$30,688,025	$463,565,102	$24.84
24	2044	$0	$435,960,956	$147,346	$31,140,495	$467,248,797	$24.91
25	2045	$0	$439,237,664	$150,263	$31,551,344	$470,939,271	$24.96
26	2046	$0	$442,230,479	$153,002	$31,929,276	$474,312,757	$25.00
27	2047	$0	$445,334,157	$155,668	$32,285,302	$477,775,127	$25.04
28	2048	$0	$448,190,015	$158,253	$32,619,841	$480,968,109	$25.08
29	2049	$0	$450,983,531	$160,763	$32,934,626	$484,078,920	$25.11
30	2050	$0	$453,904,155	$163,206	$33,232,654	$487,300,015	$25.13
31	2051	$0	$454,730,556	$165,503	$33,494,491	$488,390,550	$25.19

32	2052	$0	$455,469,747	$167,722	$33,728,697	$489,366,166	$25.24
33	2053	$0	$456,124,543	$169,851	$33,936,162	$490,230,556	$25.28
34	2054	$0	$456,712,926	$171,880	$34,122,586	$491,007,391	$25.32
35	2055	$0	$457,234,600	$173,792	$34,287,873	$491,696,266	$25.36
36	2056	$0	$457,690,833	$175,587	$34,432,426	$492,298,846	$25.39
37	2057	$0	$458,084,204	$177,260	$34,557,062	$492,818,527	$25.42
38	2058	$0	$458,395,516	$178,752	$34,655,698	$493,229,966	$25.44
39	2059	$0	$458,655,327	$180,143	$34,738,017	$493,573,487	$25.46
40	2060	$0	$458,874,218	$181,461	$34,807,370	$493,863,049	$25.47

B.3.2 The DSRC Option

This option uses DSRC radios to communicate with SCMS. New certificates and incremental CRL would be transmitted through RSE. The OBE costs (i.e., DSRC radios) were included in the early estimates. Therefore, the annual communication costs for this system were from RSE. Table VII-11 summarizes the estimated annual communication costs for this system. The annual communication costs would be up to $186 million and the annual per vehicle cost would be up to $13.53. As shown, the surged cost in Year 4 is due to the installation of the first batch of new RSE according to the RSE phase-in schedule. In the fourth year, the assumed phase-in schedule is 23 percent of the total 19,750 units. In addition, the cost surges in Years 15, 19, and 34 reflect the annual cost of replacing this equipment.

Table VII-11

Estimated Annual Communication Costs and Per Vehicle Costs

DSRC (2014 $)

Year	Calendar Year	RSE	OBE	Data Cost Satellite	Data Cost Cellular	Total	Cost Per Vehicle
1	2021	$0	$0	$0	$0	$0	$0.00
2	2022	$0	$0	$0	$0	$0	$0.00
3	2023	$0	$0	$0	$0	$0	$0.00
4	2024	$186,090,367	$0	$0	$0	$186,090,367	$11.26
5	2025	$85,882,056	$0	$0	$0	$85,882,056	$5.15
6	2026	$95,733,225	$0	$0	$0	$95,733,225	$5.72
7	2027	$105,584,395	$0	$0	$0	$105,584,395	$6.25
8	2028	$115,435,565	$0	$0	$0	$115,435,565	$6.78
9	2029	$125,286,734	$0	$0	$0	$125,286,734	$7.31
10	2030	$135,137,904	$0	$0	$0	$135,137,904	$7.81
11	2031	$144,989,074	$0	$0	$0	$144,989,074	$8.31
12	2032	$154,840,243	$0	$0	$0	$154,840,243	$8.82
13	2033	$164,691,413	$0	$0	$0	$164,691,413	$9.32
14	2034	$174,542,583	$0	$0	$0	$174,542,583	$9.78
15	2035	$184,393,752	$0	$0	$0	$184,393,752	$10.24

16	2036	$168,543,441	$0	$0	$0	$168,543,441	$9.28
17	2037	$147,767,545	$0	$0	$0	$147,767,545	$8.06
18	2038	$147,767,545	$0	$0	$0	$147,767,545	$7.99
19	2039	$252,465,284	$0	$0	$0	$252,465,284	$13.53
20	2040	$177,681,184	$0	$0	$0	$177,681,184	$9.42
21	2041	$177,681,184	$0	$0	$0	$177,681,184	$9.28
22	2042	$177,681,184	$0	$0	$0	$177,681,184	$9.57
23	2043	$177,681,184	$0	$0	$0	$177,681,184	$9.52
24	2044	$177,681,184	$0	$0	$0	$177,681,184	$9.47
25	2045	$177,681,184	$0	$0	$0	$177,681,184	$9.42
26	2046	$177,681,184	$0	$0	$0	$177,681,184	$9.37
27	2047	$177,681,184	$0	$0	$0	$177,681,184	$9.31
28	2048	$177,681,184	$0	$0	$0	$177,681,184	$9.26
29	2049	$177,681,184	$0	$0	$0	$177,681,184	$9.22
30	2050	$177,681,184	$0	$0	$0	$177,681,184	$9.16
31	2051	$162,724,365	$0	$0	$0	$162,724,365	$8.39
32	2052	$147,767,545	$0	$0	$0	$147,767,545	$7.62
33	2053	$147,767,545	$0	$0	$0	$147,767,545	$7.62
34	2054	$252,465,284	$0	$0	$0	$252,465,284	$13.02
35	2055	$177,681,184	$0	$0	$0	$177,681,184	$9.16
36	2056	$177,681,184	$0	$0	$0	$177,681,184	$9.16
37	2057	$177,681,184	$0	$0	$0	$177,681,184	$9.16
38	2058	$177,681,184	$0	$0	$0	$177,681,184	$9.16
39	2059	$177,681,184	$0	$0	$0	$177,681,184	$9.16
40	2060	$177,681,184	$0	$0	$0	$177,681,184	$9.16

C. SCMS Costs

In addition to the CDDS cost model, BAH also established a cost model for SCMS. The SCMS cost estimates presented here were based on this model. However, we made three significant revisions.

The first is the labor costs. Salaries were revised using the most current data from the Occupational Employment Statistics (OES) [136] that was published by the Bureau of Labor Statistics (BLS) as of May 2014. One of the job categories, Information Security Analysts, Web Developers, and Computer Network Architects (15-1179) that was labeled as Systems Analysis/ Engineer Associates in the original SCMS model was eliminated from the OES. Apparently, the current OES separated Web Developer from Network Architects and become an individual job category. The OES job category code for Web Developers is 15-1134 and for Network

[136] MSA_M2014 File as May 2014, www.bls.gov/oes

Architects is 15-1143. To map the new job categories to what was used by BAH, the PRIA used the weighted average salaries of these two categories. The number of employees in each category was used as the weight factor.

The second revision we made is the compensation costs. Based on the News Release on, EMPLOYER COSTS FOR EMPLOYEE COMPENSATION, March 2015 (2015 USDL-15-1132)[137], the average hourly wages for all workers in private industry is $21.94 and the average total benefit is $9.71. This indicates that the total benefit is 44.3 percent of the wages. By examining the individual job categories, the compensation percentage ranged from 36 percent to 48 percent. Therefore, we determined using the 44.3 percent to estimate the compensation costs. The 44.3 percent is significant higher than the 25 percent that was used by BAH.

The third revision is that we added the costs needed before establishing the SCMS (Year 0 costs). The Year 0 costs included the design of the SCMS physical architecture/electric/floor plan, land preparation, power source redundancy, power lines installation, and other facility- and operational-relevant preparation. The costs are estimated to be $20.8 million as one-time costs and were spread over 20 years which the agency believes is reasonable considering the long term commitment associated with SCMS development and operation. The costs also served as data center refreshing costs since lifespan of a data center is about 20 years (i.e., need to replace power structure, power generators, cooling systems, and etc.)[138]

To estimate the annual total costs for the entire SCMS, we first examined the costs for each of the 10 component functions of the SCMS. Each function, the costs comprised these five expenditure categories: Hardware Purchase, Software Purchase, Software Operation and Maintenance (Q&M), Initial Facility Costs, Annual Facility Costs, and Full Time Equivalent (FTE) Costs. The location for establishing the SCMS functions and the corresponding labor costs, energy costs, land cost, and rent cost were based on these six areas: Metro DC, Richland,

[137] Table 5 (page 10), released June 10, 2015, http://www.bls.gov/news.release/pdf/ecec.pdff

[138] Advised by a data construction expert at Gilbane Building Company

WA, Denver, CO, Chicago, IL, San Antonio, TX, Gastonia, NC. These areas covered a wide variation of costs.

Table VII-12 shows the SCMS by function, the total costs, and the cost per vehicle. These costs (only the equipment portion) have already been adjusted for learning. As shown, the total SCMS would range from $39.1 million in the first year to $160.1 million in Year 40. The SCMS per vehicle cost would range from $2.42 in 2021 to $8.29 in 2060.

Table VII-12
SCMS Costs by Function (2014 $)

Year	Calendar Year	PCA	RA	LA	MA	LOP	ECA
1	2021	$4,708,025	$10,358,634	$987,277	$3,679,694	$2,332,410	$4,381,260
2	2022	$4,672,050	$10,270,907	$988,020	$3,658,706	$2,311,587	$4,343,622
3	2023	$4,677,281	$10,274,580	$990,346	$3,658,847	$2,312,044	$4,343,622
4	2024	$4,687,633	$10,281,935	$995,076	$3,659,125	$2,312,536	$4,343,622
5	2025	$6,728,645	$13,103,893	$1,740,502	$3,889,204	$2,771,798	$4,781,464
6	2026	$4,724,254	$10,308,046	$1,011,781	$3,660,108	$2,313,639	$4,343,622
7	2027	$4,744,931	$10,322,789	$1,021,213	$3,660,663	$2,314,203	$4,343,622
8	2028	$4,765,448	$10,337,418	$1,030,571	$3,661,213	$2,314,761	$4,343,622
9	2029	$4,785,584	$10,351,775	$1,039,756	$3,661,753	$2,315,308	$4,343,622
10	2030	$10,510,180	$16,401,748	$4,799,128	$4,179,494	$3,682,299	$4,781,464
11	2031	$9,308,218	$14,856,461	$9,073,569	$5,441,652	$4,543,859	$4,343,622
12	2032	$9,327,079	$14,869,909	$9,082,173	$5,442,159	$4,544,359	$4,343,622
13	2033	$9,345,391	$14,882,966	$9,090,526	$5,442,650	$4,544,835	$4,343,622
14	2034	$9,363,032	$14,895,544	$9,098,573	$5,443,123	$4,545,288	$4,343,622
15	2035	$14,419,003	$20,996,845	$12,930,027	$5,772,704	$5,912,422	$4,781,464
16	2036	$9,395,586	$14,918,755	$9,113,422	$5,443,997	$4,546,114	$4,343,622
17	2037	$9,410,421	$14,929,333	$9,120,189	$5,444,395	$4,546,484	$4,343,622
18	2038	$9,424,185	$14,939,146	$9,126,467	$5,444,764	$4,546,824	$4,343,622
19	2039	$9,436,904	$14,948,215	$9,132,269	$5,445,106	$4,547,132	$4,343,622
20	2040	$18,633,720	$24,737,954	$15,746,265	$6,126,542	$7,214,409	$4,781,464
21	2041	$13,918,676	$19,420,803	$13,587,376	$7,223,691	$6,773,241	$4,343,622
22	2042	$13,927,310	$19,426,959	$13,591,314	$7,223,922	$6,773,441	$4,343,622
23	2043	$13,935,979	$19,433,140	$13,595,268	$7,224,155	$6,773,625	$4,343,622
24	2044	$13,943,871	$19,438,767	$13,598,868	$7,224,367	$6,773,790	$4,343,622
25	2045	$22,174,444	$29,152,824	$20,355,009	$7,633,697	$9,489,116	$4,781,464
26	2046	$13,955,521	$19,447,074	$13,604,182	$7,224,679	$6,774,061	$4,343,622
27	2047	$13,960,466	$19,450,599	$13,606,438	$7,224,812	$6,774,181	$4,343,622
28	2048	$13,964,937	$19,453,788	$13,608,477	$7,224,932	$6,774,292	$4,343,622
29	2049	$13,969,051	$19,456,721	$13,610,354	$7,225,042	$6,774,396	$4,343,622
30	2050	$26,815,885	$33,350,158	$23,655,970	$8,045,813	$11,171,981	$4,781,464
31	2051	$18,425,034	$23,909,622	$18,057,646	$9,002,835	$8,999,434	$4,343,622
32	2052	$18,428,332	$23,911,973	$18,059,151	$9,002,923	$8,999,513	$4,343,622
33	2053	$18,431,447	$23,914,194	$18,060,572	$9,003,007	$8,999,585	$4,343,622
34	2054	$18,434,213	$23,916,166	$18,061,833	$9,003,081	$8,999,649	$4,343,622
35	2055	$28,781,702	$35,756,214	$26,844,673	$9,423,600	$12,687,495	$4,781,464
36	2056	$18,438,804	$23,919,440	$18,063,928	$9,003,204	$8,999,755	$4,343,622
37	2057	$18,440,716	$23,920,803	$18,064,800	$9,003,256	$8,999,799	$4,343,622
38	2058	$18,442,316	$23,921,944	$18,065,529	$9,003,299	$8,999,834	$4,343,622
39	2059	$18,443,789	$23,922,994	$18,066,201	$9,003,338	$8,999,864	$4,343,622
40	2060	$31,518,164	$38,029,601	$28,307,710	$9,825,764	$13,480,752	$4,781,464

Table VII-12 - Continued

SCMS Costs by Function (2014 $)

Year	Calendar Year	Intermediate CA	Root CA	DCM	Manager	Total Costs	Total per Vehicle
1	2021	$4,317,570	$1,723,817	$4,378,553	$2,233,628	$39,100,867	$2.42
2	2022	$4,279,932	$1,717,795	$4,340,915	$2,231,119	$38,814,652	$2.38
3	2023	$4,279,932	$1,717,795	$4,340,915	$2,231,119	$38,826,479	$2.36
4	2024	$4,279,932	$1,717,795	$4,340,915	$2,231,119	$38,849,687	$2.35
5	2025	$4,718,684	$1,808,090	$4,760,710	$2,292,279	$46,595,268	$2.80
6	2026	$4,279,932	$1,717,795	$4,340,915	$2,231,119	$38,931,210	$2.32
7	2027	$4,279,932	$1,717,795	$4,340,915	$2,231,119	$38,977,180	$2.31
8	2028	$4,279,932	$1,717,795	$4,340,915	$2,231,119	$39,022,793	$2.29
9	2029	$4,279,932	$1,717,795	$4,340,915	$2,231,119	$39,067,558	$2.28
10	2030	$5,968,049	$1,808,090	$4,760,710	$2,557,780	$59,448,941	$3.44
11	2031	$8,455,524	$1,717,795	$4,340,915	$3,382,829	$65,464,444	$3.75
12	2032	$8,455,524	$1,717,795	$4,340,915	$3,382,829	$65,506,362	$3.73
13	2033	$8,455,524	$1,717,795	$4,340,915	$3,382,829	$65,547,052	$3.71
14	2034	$8,455,524	$1,717,795	$4,340,915	$3,382,829	$65,586,244	$3.68
15	2035	$10,890,222	$1,808,090	$4,760,710	$3,511,964	$85,783,450	$4.77
16	2036	$8,455,524	$1,717,795	$4,340,915	$3,382,829	$65,658,556	$3.62
17	2037	$8,455,524	$1,717,795	$4,340,915	$3,382,829	$65,691,506	$3.58
18	2038	$8,455,524	$1,717,795	$4,340,915	$3,382,829	$65,722,070	$3.55
19	2039	$8,455,524	$1,717,795	$4,340,915	$3,382,829	$65,750,310	$3.52
20	2040	$12,177,224	$1,808,090	$4,760,710	$3,774,067	$99,760,445	$5.29
21	2041	$12,631,117	$1,717,795	$4,340,915	$4,517,339	$88,474,574	$4.62
22	2042	$12,631,117	$1,717,795	$4,340,915	$4,517,339	$88,493,733	$4.77
23	2043	$12,631,117	$1,717,795	$4,340,915	$4,517,339	$88,512,955	$4.74
24	2044	$12,631,117	$1,717,795	$4,340,915	$4,517,339	$88,530,450	$4.72
25	2045	$17,513,413	$1,808,090	$4,760,710	$4,691,868	$122,360,635	$6.48
26	2046	$12,631,117	$1,717,795	$4,340,915	$4,517,339	$88,556,305	$4.67
27	2047	$12,631,117	$1,717,795	$4,340,915	$4,517,339	$88,567,283	$4.64
28	2048	$12,631,117	$1,717,795	$4,340,915	$4,517,339	$88,577,214	$4.62
29	2049	$12,631,117	$1,717,795	$4,340,915	$4,517,339	$88,586,351	$4.59
30	2050	$19,214,431	$1,808,090	$4,760,710	$4,691,868	$138,296,371	$7.13
31	2051	$16,806,710	$1,717,795	$4,340,915	$4,517,339	$110,120,950	$5.68
32	2052	$16,806,710	$1,717,795	$4,340,915	$4,517,339	$110,128,271	$5.68
33	2053	$16,806,710	$1,717,795	$4,340,915	$4,517,339	$110,135,185	$5.68
34	2054	$16,806,710	$1,717,795	$4,340,915	$4,517,339	$110,141,322	$5.68
35	2055	$23,459,123	$1,808,090	$4,760,710	$4,692,002	$152,995,074	$7.89
36	2056	$16,806,710	$1,717,795	$4,340,915	$4,517,339	$110,151,511	$5.68
37	2057	$16,806,710	$1,717,795	$4,340,915	$4,517,339	$110,155,754	$5.68
38	2058	$16,806,710	$1,717,795	$4,340,915	$4,517,339	$110,159,302	$5.68
39	2059	$16,806,710	$1,717,795	$4,340,915	$4,517,339	$110,162,566	$5.68
40	2060	$23,459,123	$1,808,090	$4,760,710	$4,692,026	$160,663,404	$8.29

D. Fuel Economic Impact

In addition to the cost of the equipment itself, the new equipment on vehicles will increase the vehicle weight. Since the increase in weight is relatively small, the increased weight will have only a small impact on the fuel economy of the individual vehicles on which the V2V equipment is installed. Nevertheless, over the lifetime of these vehicles, this impact on fuel economy will create a cost for society.

The fuel economic impact also has two measures: the annual fuel impact and the lifetime fuel impact for a MY vehicles (MY fuel impact). The annual fuel impact represents the collected additional fuel costs from all V2V-equipped vehicles for that year. MY fuel impact represents the additional fuel costs for a life of a MY vehicle and should be discounted.

As derived in previous sections, the primary vehicles components includes DSRC radios and relevant parts/materials (e.g., antenna, installation material, HSM etc.) and OBE for cellular, Wi-Fi and satellite. Therefore, for the Hybrid option, the total additional total weight would be 3.21 pounds which came from one-radio and relevant parts/materials (3.06 pounds) and satellite radios (0.15 pounds). Weight from cellular and Wi-Fi are negligible. For the DSRC option, the total additional weight would be 3.38 pounds which come from the two DSRC radios and relevant parts/materials. The increased weight is the same for both PCs and LTVs.

D.1 Annual Fuel Economic Impact

The impact of added weight on both annual and MY fuel economic is a function of vehicle volumes, vehicle miles traveled, survival probability (i.e., the percentage of the vehicle fleet that will not be scrapped due to an accident or for other reasons), the price of gasoline, and the change in vehicle fuel economy (i.e., change in miles per gallon) due to the added weight. We also take into account the discrepancy between actual fuel economic and the EPA's derived fuel economy (PMG factor). Finally, we also factored in the change in VMT over time. MY fuel impact also depends on the discount rate that was chosen to express lifetime impacts in their present value.

The annual fuel economic impact can be mathematically noted as:

$$F_i(k)=\sum_{j=1}^{l} P_i{*}V_j{*}S_j{*}VMT_j{*}M_i\left(\frac{1}{m{*}MPG_j^{w0_j+k}}-\frac{1}{m{*}MPG_j^{w0_j}}\right)$$

$$=\sum_{j=1}^{l} P_i{*}V_j{*}S_j{*}VMT_j{*}M_i{*}\frac{1}{m}\left(\frac{1}{MPG_{wo}-\frac{k}{w0}{*}r{*}MPG_j^{w0_j+k}}-\frac{1}{MPG_j^{w0_j}}\right)$$

$$=\sum_{j=1}^{l} P_i{*}V_j{*}S_j{*}VMT_j{*}M_i\frac{1}{m{*}MPG_j^{w0_j}}\left(\frac{w0_j}{w0_j-r{*}k}-1\right)$$

$$=\sum_{j=1}^{l} P_i{*}V_j{*}S_j{*}VMT_j{*}M_i\frac{1}{m{*}MPG_j^{w0_j}}\left(\frac{r{*}k}{w0_j-r{*}k}\right)$$

Where,

k = added weight

i = year of implementation, i.e., i =1 for 2021

j = age of the vehicles at year i

$l = \mathrm{mod}(i, L)$ for $i \leq L$ and $i = L$ for $i > L$ where L is the life of a vehicle

F_i = annual fuel economic at year i

P_i = the projected fuel price at calendar year i

V_j = vehicle volume for age j vehicles

S_j = survival probability at age j

VMT_j = miles traveled at age j

M_i = the annual VMT factor

$W0_j$ = based weigh for age j vehicles

$MPG_j^{w0_j}$ = base miles per gallon for age j vehicles

$MPG_j^{w0_j+k}$ = new miles per gallon due to added weigh k for age j vehicles

m = MPG discount factor

r = percent of MPG reduction for a 1 percent of weight increase

Of the above symbol, mod(i, L) is the modulo operation finds the remainder after the division of i by L and L is the lifespan of a vehicle. Therefore, for PCs, the index l in the above formula is the remainder of the implementation year divided by 30 if the implementation is not over 30 years. If the implementation is over 30 years, l is 30. For LTVs, the L is 37 years. Basically, l represents the number of MYs that would contribute to the fuel economy year i.

The projected fuel price (P_i) from 2018 to 2040 was taken from the agency's Greenhouse Gas Emissions and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles - Phase 2.[139] Prices from 2041 to 2065 were estimated based on a linear regression of the 2018 to 2040 prices. Fuel price was the dependent variable and the calendar year is the independent variable. The resulted linear model regression shows a good fit (adjusted R^2 = 99%) and has the following form:

$$P_i = 0.04044 * i - 79.0266$$

These predicted prices were then revised to 2014 dollars using the implicit GDP price deflator.

Projected vehicle sales volumes (V_j) were derived by using those in the ANPRM. However, the historical data seem to overestimate the recent sales. Therefore, the PRIA adjusted the projected 2013 sales in the ANPRM by the ratio of the 2013 sales published in the Ward's 2014 Automotive Yearbook to sales projected in the ANPRM. The adjustment factors were 0.89 for PCs and 1.02 for LTVs. As a result, the projected PC sales were 11 percent lower than the previously predicted level and LTVs were 2 percent higher. Table A-2 in Appendix A shows the vehicle sales from 2021 to 2050.

Survival Probability (S_j) represents the percentage of the vehicle fleet that will not be scrapped due to an accident or other factors. These probabilities were derived using the 1997-2010 R.L.

[139] Docket number NHTSA-2014-0132, fuel price derived from the Department of Energy's Annual Energy Outlook 2014

Polk, National Vehicle Population Profile (NVPP). The survivability data differ between passenger cars and light trucks. The methodology of deriving these data was documented in the agency report on vehicle survivability and travel mileage schedules.[140] Appendix A provides the survival rates for PCs and LTVs.

Vehicle Miles Traveled (VMT_j) where "j" is the VMT for vehicle at j^{th} year. The process of deriving the average VMT by age is similar to that described in the agency report on vehicle survivability and travel mileage schedules. The PRIA used 2008-based VMT by age which was derived from the 2009 National Household Travel Survey.[141] NHTSA uses VMT by age of vehicle and survivability tables to model the retirement of older vehicles as time passes and to estimate the impact of fuel economy changes over the lifetime of a model year. VMT also differs between passenger cars and light trucks

The annual VMT factor (M_i) is the increase percentage relative to the base VMT. The initial VMTs were for 2008. Based on AEO 2014, VMT per driver peaked at 12,900 miles in 2007 and decreased to 12,500 miles in 2012.[142] The report also suggested two possible VMT growth patterns. The lower VMT pattern assumed a 0.5% annual decrease and the high VMT growth pattern assumed the annual VMT increased by the following percentages: 0.3 percent for 2013, 0.4 percent for 2016, 0.5 percent for 2019, 0.6 percent for 2023, 0.5 percent for 2027, 0.4 percent for 2032, and 0.3 percent for 2036-2040. The analysis used the high growth pattern since VMT

[140] Lu, S., "Vehicle Survivability and Travel Mileage Schedules", NHTSA Technical Report, January 2006, DOT 809 952. Survivability was calculated from R.L. Polk, National Vehicle Population Profile (NVPP), 1977-2010 Polk's NVPP is an annual census of passenger cars and light trucks registered for on-road operation in the United States as of Jul 1 each year. Survival rates were averaged for the five most recent model years to reach each age up to 30 years, and polynomial models were fitted to these data using regression analysis to develop smooth relationships between age and the proportion of cars or light trucks surviving to that age.

[141] Lu, S., "Vehicle Survivability and Travel Mileage Schedules", NHTSA Technical Report, January 2006, DOT 809 952. The original source of information on annual use of passenger cars and light trucks by age used in this report is the 2001 National Household Travel Survey (NHTS), jointly sponsored by the Federal Highway Administration, Bureau of Transportation Statistics, and National Highway Traffic Safety Administration. A process similar to that described in this report was used to develop estimates of the average number of miles driven by household vehicles at each age using the sample of approximately 300,000 vehicles included in the 2009 National Household Travel Survey.

[142] Page IF-22, Annual Energy Outlook, with Projections to 2040, U.S. Energy Information Administration, Department of Energy, DOE/EIA 0383 (2014) April 2014

primarily affect the fuel economy impact and we do not want to underestimate the fuel economy impact. Based on these statistics, we estimated that VMT decreased annually by 0.63 percent from 2008 to 2012 and then increased from 2013 to 2040. The annual increase between the two years that was not specified in the AEO report was assumed to be the increase level of the early year. The PRIA used the percentage increase data to derive the annual VMT factors. In other words, M1=1 at 2021, M2 = 1+%increase over 2021 at 2022, and M3 = 1+%total increase over 2021 at 2023, and so on so forth. Since AEO 2014 only projected the VMT increase up to 2040, after 2040, the PRIA assumed VMT will stay at the 2040 level. Table VII-13 shows the annual VMT increase and the annual VMT factors. Table A-3 in Appendix A provides the projected VMT for 2021, the base VMT for fuel economic impact calculation.

Table VII-13

Annual Percent VMT Increase and the Annual VMT factor

Calendar Year	% Annual Increase	VMT Factor
2021	Base	1.000
2022	0.50%	1.005
2023	0.60%	1.011
2024	0.60%	1.017
2025	0.60%	1.023
2026	0.60%	1.029
2027	0.50%	1.034
2028	0.50%	1.040
2029	0.50%	1.045
2030	0.50%	1.050
2031	0.50%	1.055
2032	0.40%	1.060
2033	0.40%	1.064
2034	0.40%	1.068
2035	0.40%	1.072
2036	0.30%	1.076
2037	0.30%	1.079
2038	0.30%	1.082
2039	0.30%	1.085
2040	0.30%	1.088
2041 – 2060	0.00%	1.088

The baseline miles per gallon ($MPG_j^{w0_j}$) and vehicle baseline weight ($w0_j$) were based on the agency's 2012 fuel economic final rule for MY 2021 to 2025. The baseline weight ($w0_j$) represents the baseline curb weight for a MY vehicle that is j years old for a specific year. Table

VII-14 shows the MPG and $w0_j$ from MY 2021 to MY 2025. The PRIA assumes that fuel economy and the curb weight for MY vehicles produced after 2025 are at the 2025 levels. For example, at year 2026, MY 2021 to MY 2026 vehicles would contribute to the fuel economy impact. The baseline MPG for MY 2021 (i.e., $MPG_6^{w0_6}$) to MY 2025 (i.e., $MPG_2^{w0_2}$) were those shown in the table below. For MY 2026 and newer, the baseline MPG (i.e., $MPG_1^{w0_1}$) would be those for MY 2025.

Table VII-14

Vehicle Base Weight and Corresponding Fuel Economy

Year	Vehicle Base Weight* ($w0_j$ in pounds)		Base Miles per Gallon ($MPG_j^{w0_j}$)	
	PCs	LTVs	PCs	LTVs
2021	3196	4107	49.00	38.00
2022	3194	4084	50.00	39.00
2023	3194	4071	52.00	40.00
2024	3191	4046	54.00	41.00
2025	3191	4011	56.00	43.00
2026 - 2060	3191	4011	56.00	43.00

*curb weight

The MPG discount factor (m) reflects the discrepancy between the on-road fuel economy and that established by the Environmental Protection Agency (EPA). Fuel economy is determined according to procedures established by the EPA. However, the EPA estimates that actual on-road fuel economy is overall 20 percent less than the EPA's calculated fuel economy. Therefore, the actual MPH is 80 percent of that established by the EPA, i.e., m = 0.8. Thus, actual $MPG_j^{w0_j} = 0.8 * MPG_j^{w0_j}$ and actual $MPG_j^{w0_j+k}$=0.8 * $MPG_j^{w0_j+k}$.

The weight reduction impact on fuel economy (r) was based on the Ricardo study.[143] The study showed that one percent of mass reduction for passenger vehicles with gasoline engines would improve its fuel economy by 0.33 percent. This mass reduction and fuel economy improvement

[143] Page 59 of the study, http://www.drivealuminum.org/research-resources/PDF/Research/2008/2008-Ricardo-Study.pdf

(or reduction) also was cited by the latest NAS report.[144] Therefore, 0.33 percent was used to estimate the new MPG at the added weight (MPG_{w0+k}), i.e., r = 0.33.

Substituting 0.8 for m and 0.33 for r, the above formula became:

$$F_i(k) = \sum_{j=1}^{l} P_i{}^*V_j{}^*S_j{}^*VMT_j{}^*M_i \frac{1}{0.8^*MPG_j^{w0_j}}\left(\frac{0.33k}{w0_j\text{-}033k}\right)$$

Since PVs and LTVs have different vehicle life, vehicle weight, and MPG, $F_i(k)$ is calculated separately for PCs and LTVs and these F_i are additive The combined F_i is the total annual fuel impact. Table VII-15 shows the annual fuel economy impact for both one-radio with the Hybrid option and two radios with the DSRC option. Note that the weight difference between the two-radio system and the one-radio system is 0.17 pound. This small weight difference resulted in non-discernable difference between these two technology approaches under the rounding rule used by the PRIA. To be consistent with the measure used for other cost items, the "per vehicle" cost was estimated to be the cost per a new vehicle. As shown, the proposed rule would increase the current total annual fuel consumption by 1.10 million gallons in 2021 to 30.51 million gallons in 2060. The corresponding annual cost for these additional fuels was estimated to be \$3.08 to \$135.16 million, annually. These amounts were translated into \$0.19 to \$6.97 per new vehicle sold.

[144] Page 6-26 (pre-public version). http://our.dot.gov/office/nhtsa.nvs/NVS-100/NVS-130/NVS-132/Shared%20Documents/CAFE%20LD/NRC%20Committee%20LDVs/Cost,%20Effectiveness%20and%20Deployment%20of%20Fuel%20Economy%20Technologies%20for%20Light-Duty%20Vehicles%20Prepublication%20Report%206-12-15.pdf

Table VII-15

Annual Fuel Economy Impact* (2014 $)

Year	Calendar Year	Fuel Price	Additional Gallons (Million)	Total Fuel Economy (Million $)	Per Vehicle Cost ($)
1	2021	$2.80	1.10	$3.08	$0.19
2	2022	$2.86	2.69	$7.69	$0.47
3	2023	$2.91	4.70	$13.68	$0.83
4	2024	$2.95	6.58	$19.41	$1.17
5	2025	$2.99	8.34	$24.94	$1.50
6	2026	$3.02	10.02	$30.26	$1.81
7	2027	$3.06	11.66	$35.68	$2.11
8	2028	$3.08	13.19	$40.63	$2.39
9	2029	$3.11	14.62	$45.47	$2.65
10	2030	$3.14	16.01	$50.27	$2.91
11	2031	$3.18	17.32	$55.08	$3.16
12	2032	$3.22	18.52	$59.63	$3.40
13	2033	$3.26	19.69	$64.19	$3.63
14	2034	$3.35	20.73	$69.45	$3.89
15	2035	$3.38	21.76	$73.55	$4.09
16	2036	$3.43	22.68	$77.79	$4.28
17	2037	$3.47	23.50	$81.55	$4.45
18	2038	$3.51	24.28	$85.22	$4.61
19	2039	$3.58	24.99	$89.46	$4.79
20	2040	$3.66	25.64	$93.84	$4.97
21	2041	$3.64	26.27	$95.62	$5.00
22	2042	$3.68	26.70	$98.26	$5.29
23	2043	$3.72	27.11	$100.85	$5.40
24	2044	$3.76	27.46	$103.25	$5.50
25	2045	$3.80	27.83	$105.75	$5.60
26	2046	$3.84	28.11	$107.94	$5.69
27	2047	$3.88	28.44	$110.35	$5.78
28	2048	$3.93	28.71	$112.83	$5.88
29	2049	$3.97	28.91	$114.77	$5.95
30	2050	$4.01	29.21	$117.13	$6.04
31	2051	$4.06	29.43	$119.49	$6.16
32	2052	$4.10	29.65	$121.57	$6.27
33	2053	$4.14	29.82	$123.45	$6.37
34	2054	$4.18	29.97	$125.27	$6.46
35	2055	$4.22	30.10	$127.02	$6.55
36	2056	$4.27	30.20	$128.95	$6.65
37	2057	$4.31	30.33	$130.72	$6.74
38	2058	$4.35	30.41	$132.28	$6.82
39	2059	$4.39	30.47	$133.76	$6.90
40	2060	$4.43	30.51	$135.16	$6.97

*for both one-radio and two-radios approaches

VII-16 presents the estimated fuel economy separately for PCs and LTVs. As shown, the total annual fuel economy cost ranged from $1.32 to $55.64 million for PCs and $1.76 to $79.52 million for LTVs. The cost per vehicle ranged from $0.16 to $5.82 for PCs and 0.22 to $8.09 for LTVs.

Table VII-16
Annual Fuel Economy Impact* by Vehicle Type (2014 $)

Year	Calendar Year	Additional Gallons (Million)		Total Fuel Economy (Million $)		Per Vehicle Cost ($)	
		PCs	LTVs	PCs	LTVs	PCs	LTVs
1	2021	0.47	0.63	$1.32	$1.76	$0.16	$0.22
2	2022	1.15	1.54	$3.29	$4.40	$0.39	$0.55
3	2023	2.02	2.68	$5.88	$7.80	$0.70	$0.97
4	2024	2.82	3.76	$8.32	$11.09	$0.99	$1.37
5	2025	3.59	4.75	$10.73	$14.20	$1.26	$1.74
6	2026	4.32	5.70	$13.05	$17.21	$1.53	$2.10
7	2027	5.06	6.60	$15.48	$20.20	$1.80	$2.44
8	2028	5.73	7.46	$17.65	$22.98	$2.03	$2.76
9	2029	6.36	8.26	$19.78	$25.69	$2.26	$3.06
10	2030	6.97	9.04	$21.89	$28.39	$2.48	$3.35
11	2031	7.54	9.78	$23.98	$31.10	$2.70	$3.64
12	2032	8.08	10.44	$26.02	$33.62	$2.91	$3.90
13	2033	8.60	11.09	$28.04	$36.15	$3.11	$4.17
14	2034	9.08	11.65	$30.42	$39.03	$3.34	$4.47
15	2035	9.55	12.21	$32.28	$41.27	$3.52	$4.68
16	2036	9.97	12.71	$34.20	$43.60	$3.69	$4.90
17	2037	10.35	13.15	$35.91	$45.63	$3.84	$5.08
18	2038	10.69	13.59	$37.52	$47.70	$3.98	$5.27
19	2039	10.99	14.00	$39.34	$50.12	$4.14	$5.48
20	2040	11.26	14.38	$41.21	$52.63	$4.28	$5.69
21	2041	11.53	14.74	$41.97	$53.65	$4.30	$5.72
22	2042	11.63	15.07	$42.80	$55.46	$4.66	$5.91
23	2043	11.76	15.35	$43.75	$57.10	$4.74	$6.06
24	2044	11.87	15.59	$44.63	$58.62	$4.81	$6.18
25	2045	11.96	15.87	$45.45	$60.31	$4.88	$6.31
26	2046	12.04	16.07	$46.23	$61.71	$4.93	$6.43
27	2047	12.13	16.31	$47.06	$63.28	$5.00	$6.55
28	2048	12.20	16.51	$47.95	$64.88	$5.07	$6.68
29	2049	12.24	16.67	$48.59	$66.18	$5.11	$6.77
30	2050	12.32	16.89	$49.40	$67.73	$5.17	$6.89
31	2051	12.35	17.08	$50.14	$69.34	$5.24	$7.05
32	2052	12.41	17.24	$50.88	$70.68	$5.32	$7.19
33	2053	12.43	17.39	$51.46	$71.99	$5.38	$7.32
34	2054	12.46	17.51	$52.08	$73.19	$5.45	$7.45
35	2055	12.50	17.60	$52.75	$74.27	$5.52	$7.56
36	2056	12.51	17.69	$53.42	$75.54	$5.59	$7.68

37	2057	12.54	17.79	$54.05	$76.67	$5.65	$7.80
38	2058	12.57	17.84	$54.68	$77.60	$5.72	$7.89
39	2059	12.56	17.91	$55.14	$78.62	$5.77	$8.00
40	2060	12.56	17.95	$55.64	$79.52	$5.82	$8.09

*for both one-radio and two-radio approaches

D.2 MY Fuel Economy Impact

MY fuel cost (i.e., lifetime fuel economy cost) is the cost of additional gasoline used over the vehicle's life and is estimated on a per vehicle basis. The fuel economy cost for a MY vehicle was derived by applying the MY fuel economy cost per vehicle to every vehicle. The cost is accrued throughout the vehicle's life and is discounted to reflect its present value (in 2014 dollars) with 3% and 7% discount rates. As described in the annual fuel economy impact, MY fuel economy impact also is a function of mileage, survival probability (i.e., the percentage of the vehicle fleet that will not be scrapped due to an accident or for other reasons), the price of gasoline, the change in vehicle fuel economy due to the added weight, and the discount rate chosen to express lifetime impacts in their present value.

The process of deriving the MY fuel economy is similar to that of the annual fuel economy. The difference is that MY fuel economy is for the lifetime of a MY vehicle, therefore all ages in the lifespan of that MY vehicles were included in the analysis. Note that the baseline MPG (MPG^{w0}) and baseline weight (w0) do not vary with the age of the vehicle, as did in the annual fuel economy impact where different age of vehicles represents different MY vehicles. Other than discounting to the present value, the remaining processes are identical. The remaining processes include adjusting VMT by applying the VMT factors, discounting the EPA derived MPG by 20 percent, and implementing the relationship of mass reduction to fuel economy reduction (i.e., the factor of 0.33). Therefore, the MY fuel economy can be represented by the following generic formula:

$$F(k) = \sum_{j=1}^{L} P_j{*}V_j{*}S_j{*}VMT_j{*}M_j \frac{1}{0.8{*}MPG^{w0}}\left(\frac{0.33k}{w0\text{-}033k}\right) d_j$$

Where, F(k) = MY fuel economic for any vehicles
d_j = mid-point discount factor either at 3 or 7 percent
Other variables = same as those describe earlier.

Table VII-17 shows the MY fuel economy impact. As shown, at 3 percent discount, the MY fuel economy impact was estimated to be $32.75 million for MY 2021. The fuel impact gradually increases to $104.73 million for MY 2050 vehicles. The cost per vehicle was estimated to be $2.02 for MY 2021 and $5.40 for MY 2050 vehicles. The increase in fuel cost in the future, especially after the third year when the full adoption of DSRC radios starts, was primarily due to the projected higher fuel prices and vehicle sales. The cost per vehicle for a particular MY vehicle was calculated by dividing the total fuel cost for that MY by the total vehicle sales of that MY vehicle. For the first two years, due to the partial adoption, the cost per vehicle is smaller than the cost per affected vehicle since cost per vehicle as defined is the average cost over all new vehicles.

At a 7 percent discount rate, the MY fuel economy impact was estimated to be $25.03 million for MY 2021 and $80.52 million for MY 2050 vehicles. The respective cost per vehicle for these two MY vehicles would be $1.55 and $4.15 for MY 2021 and MY 2050 vehicles, respectively.

Table VII-18 shows the MY fuel economy impact by vehicle type.

Table VII-17

MY Fuel Economy Impact* by Discount Rate (2014 $)

Year	Model Year	Gallons per Vehicle	Total Gallons (Million)	MY Fuel Economy Impact (Million $)		Per Vehicle Cost	
				@3%	**@7%**	**@3%**	**@7%**
1	2021	0.83	13.38	$32.75	$25.03	$2.02	$1.55
2	2022	1.22	19.88	$49.33	$37.71	$3.02	$2.31
3	2023	1.58	26.01	$65.34	$49.96	$3.97	$3.04
4	2024	1.54	25.52	$64.90	$49.62	$3.93	$3.00
5	2025	1.49	24.80	$63.85	$48.81	$3.83	$2.93
6	2026	1.50	25.07	$65.31	$49.92	$3.90	$2.98
7	2027	1.50	25.39	$66.95	$51.17	$3.97	$3.03
8	2028	1.51	25.74	$68.69	$52.50	$4.03	$3.08
9	2029	1.52	26.03	$70.32	$53.74	$4.11	$3.14
10	2030	1.53	26.42	$72.30	$55.27	$4.18	$3.19
11	2031	1.53	26.77	$74.21	$56.74	$4.26	$3.25
12	2032	1.54	27.06	$76.00	$58.14	$4.33	$3.31
13	2033	1.55	27.34	$77.77	$59.52	$4.40	$3.37
14	2034	1.55	27.71	$79.86	$61.15	$4.48	$3.43
15	2035	1.56	28.07	$81.82	$62.67	$4.55	$3.48
16	2036	1.56	28.40	$83.76	$64.18	$4.61	$3.53
17	2037	1.57	28.77	$85.80	$65.76	$4.68	$3.59
18	2038	1.57	29.09	$87.73	$67.25	$4.74	$3.64
19	2039	1.58	29.45	$89.80	$68.86	$4.81	$3.69
20	2040	1.58	29.87	$92.00	$70.56	$4.88	$3.74
21	2041	1.58	30.30	$94.14	$72.18	$4.92	$3.77
22	2042	1.59	29.53	$92.69	$71.07	$4.99	$3.83
23	2043	1.59	29.69	$94.15	$72.20	$5.05	$3.87
24	2044	1.59	29.85	$95.63	$73.36	$5.10	$3.91
25	2045	1.59	30.03	$97.17	$74.56	$5.15	$3.95
26	2046	1.59	30.19	$98.66	$75.72	$5.20	$3.99
27	2047	1.59	30.37	$100.21	$76.94	$5.25	$4.03
28	2048	1.59	30.53	$101.73	$78.14	$5.30	$4.07
29	2049	1.59	30.69	$103.20	$79.30	$5.35	$4.11
30	2050	1.59	30.87	$104.73	$80.52	$5.40	$4.15

Table VII-18

MY Fuel Economy Impact by Vehicle Type and Discount Rate (2014 $)

Year	Model Year	Gallon per Vehicle		Total Gallons (Million)		Total Fuel Cost (Million $)			
						@3 Percent		**@7 Percent**	
		PCs	LTVs	PCs	LTVs	PCs	LTVs	PCs	LTVs
1	2021	0.69	0.96	5.73	7.65	$14.12	$18.63	$10.89	$14.14
2	2022	1.03	1.42	8.54	11.34	$21.35	$27.97	$16.47	$21.25
3	2023	1.32	1.85	11.08	14.92	$28.06	$37.28	$21.64	$28.32
4	2024	1.28	1.82	10.80	14.72	$27.68	$37.22	$21.35	$28.27
5	2025	1.24	1.74	10.56	14.24	$27.40	$36.44	$21.13	$27.68
6	2026	1.25	1.75	10.68	14.40	$28.03	$37.28	$21.61	$28.31
7	2027	1.26	1.76	10.82	14.57	$28.75	$38.20	$22.16	$29.01
8	2028	1.26	1.77	10.97	14.77	$29.51	$39.18	$22.75	$29.75
9	2029	1.27	1.78	11.09	14.93	$30.21	$40.11	$23.29	$30.46
10	2030	1.28	1.79	11.25	15.17	$31.04	$41.26	$23.93	$31.34
11	2031	1.28	1.80	11.39	15.37	$31.85	$42.36	$24.56	$32.18
12	2032	1.29	1.81	11.52	15.54	$32.61	$43.38	$25.16	$32.98
13	2033	1.29	1.81	11.64	15.69	$33.40	$44.38	$25.77	$33.75
14	2034	1.30	1.82	11.80	15.90	$34.31	$45.55	$26.49	$34.66
15	2035	1.30	1.83	11.96	16.11	$35.15	$46.68	$27.14	$35.53
16	2036	1.31	1.83	12.10	16.31	$35.98	$47.79	$27.79	$36.39
17	2037	1.31	1.84	12.25	16.52	$36.85	$48.96	$28.47	$37.29
18	2038	1.31	1.84	12.39	16.70	$37.69	$50.04	$29.13	$38.12
19	2039	1.32	1.85	12.53	16.92	$38.55	$51.24	$29.80	$39.06
20	2040	1.32	1.85	12.72	17.15	$39.52	$52.48	$30.55	$40.01
21	2041	1.32	1.85	12.90	17.39	$40.46	$53.69	$31.27	$40.92
22	2042	1.32	1.85	12.14	17.39	$38.45	$54.24	$29.72	$41.35
23	2043	1.32	1.85	12.20	17.49	$39.07	$55.08	$30.20	$42.00
24	2044	1.32	1.85	12.26	17.60	$39.64	$55.99	$30.65	$42.71
25	2045	1.32	1.85	12.32	17.71	$40.27	$56.91	$31.14	$43.42
26	2046	1.32	1.85	12.39	17.80	$40.89	$57.77	$31.63	$44.10
27	2047	1.32	1.85	12.45	17.91	$41.52	$58.69	$32.12	$44.82
28	2048	1.32	1.85	12.51	18.02	$42.11	$59.62	$32.59	$45.55
29	2049	1.32	1.85	12.57	18.12	$42.73	$60.47	$33.08	$46.22
30	2050	1.32	1.85	12.64	18.23	$43.35	$61.38	$33.57	$46.95

E. Summary of Total Quantified Costs of the Proposed Rule

E.1 Total Annual Costs

The total costs are the sum of the four cost components: vehicle equipment, communication, SCMS, and fuel economy. Table VII-19 shows the total annual costs and total annual cost per vehicle. As shown, the total annual costs of the proposed rule ranged from $2.19 (lower bound at Year 1) to $4.98 billion (upper bound at Year 4). The annual cost per vehicle would range from $135.38 to $301.31 in 2014 dollars. The lower bound of the costs represents the total costs for the one radio approach and the upper bound represents the total cost for the two-radio approach. The lower end of costs peaked at year 3 because the full adoption of DSRC radios would occur in the third year. Note that the upper end of costs peaked at the fourth year due to the surge in communication costs from the installation of RSEs.

Table VII-19

Total Annual Costs and Cost Per Vehicle (2014 $)

Year	Calendar Year	Annual Cost (Million $)		Annual Cost per Vehicle	
		Low	High	Low	High
1	2021	$2,191.73	$2,863.85	$135.38	$176.89
2	2022	$3,011.39	$3,926.44	$184.30	$240.30
3	2023	$3,832.35	$4,945.86	$233.11	$300.84
4	2024	$3,741.15	$4,980.70	$226.32	$301.31
5	2025	$3,701.10	$4,803.10	$222.02	$288.13
6	2026	$3,655.18	$4,734.53	$218.22	$282.66
7	2027	$3,640.20	$4,705.36	$215.65	$278.75
8	2028	$3,634.16	$4,689.96	$213.40	$275.39
9	2029	$3,622.11	$4,668.39	$211.45	$272.53
10	2030	$3,649.18	$4,692.05	$210.94	$271.22
11	2031	$3,659.33	$4,698.81	$209.82	$269.43
12	2032	$3,662.06	$4,698.59	$208.55	$267.57
13	2033	$3,665.05	$4,699.44	$207.42	$265.96
14	2034	$3,682.06	$4,718.70	$206.39	$264.50
15	2035	$3,717.37	$4,756.71	$206.52	$264.26
16	2036	$3,713.49	$4,730.77	$204.49	$260.51
17	2037	$3,733.84	$4,726.00	$203.59	$257.69
18	2038	$3,749.02	$4,736.11	$202.76	$256.14
19	2039	$3,768.99	$4,857.52	$201.98	$260.32
20	2040	$3,830.85	$4,844.03	$203.01	$256.71
21	2041	$3,856.11	$4,872.26	$201.47	$254.56
22	2042	$3,737.09	$4,714.95	$201.35	$254.04
23	2043	$3,744.45	$4,718.73	$200.67	$252.88
24	2044	$3,751.94	$4,723.12	$200.00	$251.77
25	2045	$3,795.51	$4,764.45	$201.14	$252.49

26	2046	$3,769.63	$4,736.16	$198.72	$249.67
27	2047	$3,779.91	$4,744.79	$198.11	$248.68
28	2048	$3,788.76	$4,751.74	$197.54	$247.74
29	2049	$3,797.35	$4,758.66	$196.96	$246.82
30	2050	$3,858.10	$4,818.41	$198.97	$248.50
31	2051	$3,821.57	$4,761.03	$197.09	$245.54
32	2052	$3,813.29	$4,732.21	$196.66	$244.05
33	2053	$3,805.14	$4,718.74	$196.24	$243.36
34	2054	$3,797.21	$4,810.45	$195.83	$248.09
35	2055	$3,832.35	$4,765.98	$197.65	$245.80
36	2056	$3,782.22	$4,711.25	$195.06	$242.97
37	2057	$3,775.03	$4,699.67	$194.69	$242.38
38	2058	$3,767.82	$4,688.30	$194.32	$241.79
39	2059	$3,760.74	$4,677.25	$193.95	$241.22
40	2060	$3,804.29	$4,716.99	$196.20	$243.27

Figure VII-2 depicts the annual costs from 2021 to 2060. The upper curve represents the high cost estimates that correspond to the two-radio approach (i.e., pairing with the DSRC communication). The lower curve represents the low cost estimates that correspond to the one-radio approach.

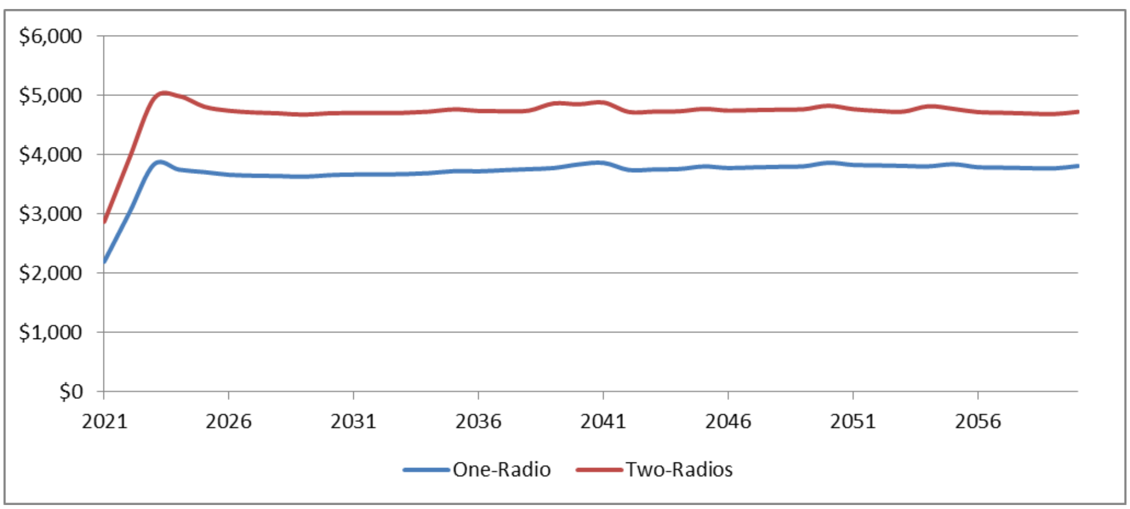

Figure VII-2
Annual Costs of the Proposed Rule from 2021 to 2060

E.2 Total MY Costs

The total costs are the sum of the four cost components: vehicle equipment, communication, SCMS, and fuel economy. As described previously, the fuel economy impact is the only difference between the annual costs and MY costs. Table VII-20 shows the total MY costs and cost per vehicle at 3 percent discount, and Table VII-21 shows the same information at 7 percent discount. As shown, at 3 percent, the total MY costs of the proposed rule ranged from $2.22 (lower bound at Year 1) to $5.03 billion (upper bound at Year 4). The MY cost per vehicle would range from $137.21 to $304.06 in the first and 4th year, respectively. The lower bound of the costs represents the total costs for the one radio approach and the upper bound represents the total cost for the two-radio approach.

At a 7 percent discount rate, the total MY costs of the proposed rule ranged from $2.21 (lower bound at Year 1) to $5.01 billion (upper bound at Year 4). The MY cost per vehicle would range from $136.73 to $303.14.

Table VII-20
Total MY Costs and Cost Per Vehicle
(**@3 Percent** Discount, 2014 $)

Year	Model Year	Total MY Cost (Million $)		MY Cost per Vehicle	
		Low	High	Low	High
1	2021	$2,221.39	$2,893.52	$137.21	$178.72
2	2022	$3,053.02	$3,968.08	$186.84	$242.84
3	2023	$3,884.01	$4,997.52	$236.25	$303.99
4	2024	$3,786.63	$5,026.18	$229.08	$304.06
5	2025	$3,740.01	$4,842.01	$224.36	$290.46
6	2026	$3,690.23	$4,769.58	$220.31	$284.75
7	2027	$3,671.47	$4,736.63	$217.50	$280.61
8	2028	$3,662.23	$4,718.02	$215.05	$277.04
9	2029	$3,646.96	$4,693.24	$212.90	$273.98
10	2030	$3,671.21	$4,714.08	$212.21	$272.49
11	2031	$3,678.46	$4,717.95	$210.92	$270.52
12	2032	$3,678.43	$4,714.96	$209.48	$268.51
13	2033	$3,678.63	$4,713.02	$208.19	$266.72
14	2034	$3,692.47	$4,729.11	$206.98	$265.08
15	2035	$3,725.64	$4,764.99	$206.98	$264.72
16	2036	$3,719.46	$4,736.74	$204.82	$260.83
17	2037	$3,738.10	$4,730.26	$203.82	$257.92
18	2038	$3,751.52	$4,738.62	$202.89	$256.28
19	2039	$3,769.32	$4,857.85	$202.00	$260.33
20	2040	$3,829.01	$4,842.19	$202.92	$256.61

21	2041	$3,854.63	$4,870.78	$201.39	$254.48
22	2042	$3,731.52	$4,709.39	$201.05	$253.74
23	2043	$3,737.75	$4,712.04	$200.31	$252.52
24	2044	$3,744.33	$4,715.51	$199.59	$251.36
25	2045	$3,786.93	$4,755.86	$200.68	$252.03
26	2046	$3,760.35	$4,726.88	$198.23	$249.18
27	2047	$3,769.78	$4,734.65	$197.58	$248.15
28	2048	$3,777.66	$4,740.64	$196.96	$247.17
29	2049	$3,785.78	$4,747.09	$196.36	$246.22
30	2050	$3,845.70	$4,806.01	$198.33	$247.86

Table VII-21
Total MY Costs and Cost Per Vehicle
(**@7 Percent** Discount, 2014 $)

Year	Calendar Year	Total MY Cost (Million $)		MY Cost per Vehicle	
		Low	High	Low	High
1	2021	$2,213.68	$2,885.80	$136.73	$178.25
2	2022	$3,041.41	$3,956.46	$186.13	$242.13
3	2023	$3,868.62	$4,982.14	$235.32	$303.05
4	2024	$3,771.35	$5,010.90	$228.15	$303.14
5	2025	$3,724.97	$4,826.97	$223.45	$289.56
6	2026	$3,674.84	$4,754.19	$219.39	$283.83
7	2027	$3,655.69	$4,720.85	$216.57	$279.67
8	2028	$3,646.03	$4,701.83	$214.09	$276.09
9	2029	$3,630.38	$4,676.66	$211.93	$273.01
10	2030	$3,654.18	$4,697.04	$211.22	$271.51
11	2031	$3,661.00	$4,700.48	$209.92	$269.52
12	2032	$3,660.57	$4,697.09	$208.46	$267.49
13	2033	$3,660.38	$4,694.77	$207.15	$265.69
14	2034	$3,673.77	$4,710.41	$205.93	$264.04
15	2035	$3,706.49	$4,745.84	$205.92	$263.66
16	2036	$3,699.88	$4,717.16	$203.74	$259.76
17	2037	$3,718.05	$4,710.22	$202.73	$256.83
18	2038	$3,731.05	$4,718.15	$201.79	$255.17
19	2039	$3,748.39	$4,836.91	$200.88	$259.21
20	2040	$3,807.57	$4,820.75	$201.78	$255.47
21	2041	$3,832.67	$4,848.82	$200.24	$253.33
22	2042	$3,709.90	$4,687.77	$199.89	$252.57
23	2043	$3,715.80	$4,690.09	$199.13	$251.34
24	2044	$3,722.05	$4,693.23	$198.40	$250.17
25	2045	$3,764.31	$4,733.25	$199.49	$250.83
26	2046	$3,737.41	$4,703.94	$197.02	$247.97
27	2047	$3,746.51	$4,711.38	$196.36	$246.93
28	2048	$3,754.07	$4,717.05	$195.73	$245.94
29	2049	$3,761.88	$4,723.19	$195.12	$244.98
30	2050	$3,821.49	$4,781.80	$197.09	$246.61

Figure VII-3 depicts the MY costs at a 3 percent discount rate for MY 2021 to MY 2050 vehicles. The upper curve represents the high cost estimates that correspond to the two-radio approach (i.e., pairing with the DSRC communication). The lower curve represents the low cost estimates that correspond to the one-radio approach. As shown, these curves are very similar to those depicted in Figure VII-2 since the difference between the annual and MY costs is the fuel economy impact. Fuel economic impact comprises a very small portion of the overall costs. The MY costs at a 7 percent discount rate does not vary significantly from those discounted at 3 percent. Therefore, the graphic presentation for the MY costs at a 7 percent discount rates is almost identical to Figure VII-3 and is not provided here.

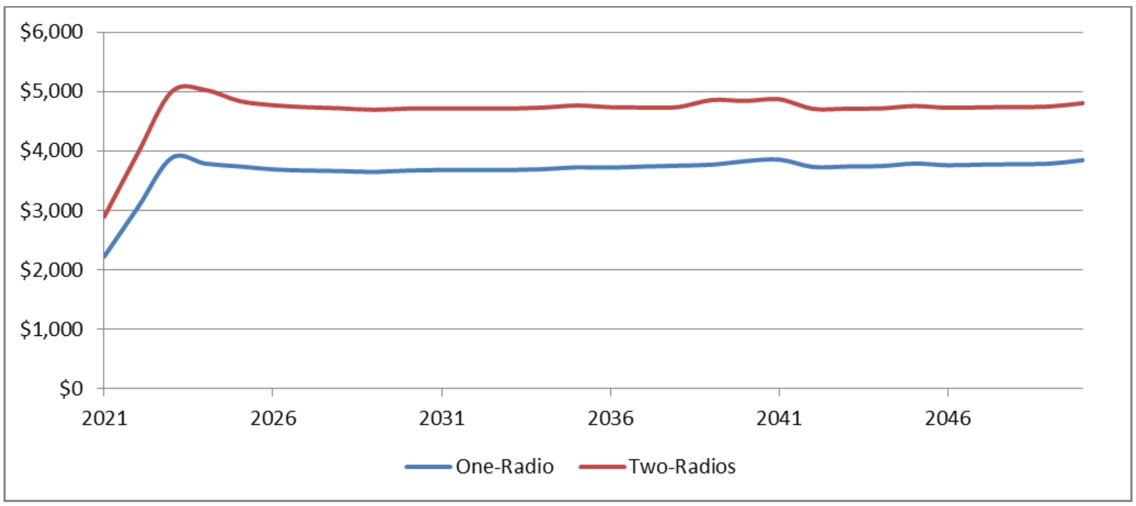

Figure VII-3
MY Costs of the Proposed Rule for MY 2021 to MY 2050 Vehicles
3 Percent Discount

F. Non-Quantified Costs

The agency identified four possibly major non-quantified costs. These include health insurance costs due to an increase in electromagnetic hypersensitivity (EHS, i.e., human radiation exposure to wireless communications), perceived loss of privacy, opportunity costs of using the spectrum for something else, and possibly increased litigation costs.

Health Costs Relating to EHS

Many commenters (mostly individual citizens) brought the potential relationship of V2V technology to EHS to our attention. The agency takes these concerns very seriously. The agency since has conducted a literature review and other research (on-going) to better understand electromagnetic radiation and its relationship to the symptoms of EHS. As we understand that the expertise of our sister agencies such as the Federal Communications Commission (FCC) and the Food and Drug Administration (FDA), among others, have been involved with electromagnetic fields, in parallel with the pervasiveness of cellular phone deployment in the United States and globally.

The FDA found that the most studies conducted to date show no connection between certain health problems and the exposure to radiofrequency fields via cell phone use and that attempts to replicate and confirm the few studies that did show a connection have failed.[145] Furthermore, V2V devices would operate at distances significantly further than the distance between a portable cellular phone to its operator, where the device is generally carried on a person or pressed directly to the ear. Therefore, the EHS effects are expected to be lower for V2V than cell phones; the agency does not quantify the health costs relating to EHS. Nevertheless, the agency acknowledges that research is still ongoing and, as technology evolves, wireless communications will most likely continue to increase. We will continue to monitor the progress of this issue and closely follow the efforts of the Radiofrequency Interagency Work Group (RFIAWG) which may yield any potential future guidance for wireless device deployment and usage.

Perceived Privacy Loss

One intangible outcome of the proposed rule is perceived potential for loss of privacy. Individuals may perceive the V2V system as eroding their personal privacy and view this as a negative consequence. Also, several surveys showed that individual attitudes towards information security seems inconsistent with their behavior on protection of their

[145] Radiation-Emitting Products, “Current Research Results,” http://www.fda.gov/Radiation-EmittingProducts/RadiationEmittingProductsandProcedures/HomeBusinessandEntertainment/CellPhones/ucm116335.htm, last accessed: June 3, 2015.

information.[146,147] Acquisti, et al. stated that identifying the consequence of a privacy incident is difficult enough, and quantifying these consequences is remarkably complex.[148] Furthermore, there are few studies on the economic costs for privacy and even less for quantifying the economic costs for perceived loss of privacy. Given the great uncertainties for valuing the perceived privacy loss, this analysis does not quantify this cost.

To ease the privacy concerns and mitigate potential consumer privacy risks, the agency is committed to regulating V2V communications in a manner that both protects individuals and promotes this important safety technology. NHTSA has worked closely with experts and our industry research partners (CAMP and the VIIC) to build privacy protections in to the design and deployment of V2V communications that helps guard against risks to individual privacy.

The agency has conducted a detailed privacy impact assessment as required by the Consolidated Appropriations Act, 2005, Pub. L. 108-447. This Act requires that Federal agencies conduct privacy impact assessments (PIAs) of proposed regulatory activities involving collections or systems of information in electronic form with the potential to impact individual privacy. A PIA documents the flow of information and information requirements within a system by detailing how and why information is transmitted, collected, stored and shared to: 1) ensure compliance with applicable legal, regulatory, and policy requirements regarding privacy; ii) determine the risks and effects of the proposed data transactions; and iii) examine and evaluate protections and alternative processes for handling data to mitigate potential privacy risks.

<u>Opportunity Costs of Spectrum for Other Use</u>

Our analysis shows that this rule will generate significant net benefits due to improved safety, decreased loss of life, reduced property damage, and other impacts. While requiring this

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[146] Acquisti, Alessandro (2004), Privacy Attitudes and Privacy Behavior, Losses, Gains, and Hyperbolic Discounting (Preliminary draft)

[147] Acquisti, Alessandro (2002). Protecting privacy with economics: Economic incentives for preventing technologies in ubiquitous computing environments. In workshop on Socially-informed Design of Privacy-enhancing Solutions, 4th International Conference on Obiquitous Computing – UBICOMP'02

[148] Acquisti, A., Friedman, A., Telang, R., "Is there a Cost to Privacy Breaches? An Event Study", Twenty Seventh International Conference on Information System, Milwaukee 2006 (pre-proceeding draft version)

technology has costs, the analysis here shows that the benefits of this rule well justify those costs.

As discussed in greater detail elsewhere in this notice, the FCC designated the 5.9 GHz band (i.e., 5850 – 5925 MHz) for ITS radio services and adopted open license to both public safety and non-public safety use of this band with the priority for public safety communications in 2003. Within the 5.9 GHz band, the FCC has designated Channel 172 (i.e., 5.855-5.865 GHz, a 10 MHz band) exclusively for “vehicle-to-vehicle communication for crash avoidance and mitigation, and safety of life and property applications.”

Given the FCC’s decision about how to allocate Channel 172, this proposed rule results in the use of that particular radio spectrum for vehicle-to-vehicle communication even though that resource could potentially have alternative uses for society including alternative safety applications. The FCC, not NHTSA or DOT, has the authority to determine the commercial use of spectrum. However, NHTSA understands the scarcity of spectrum and in the interests of providing a complete analysis of the costs and benefits of this rule seeks comment on the potential costs associated with the lost opportunity to exploit the spectrum at issue for other uses.

The FCC, as part of its own ongoing rulemaking proceeding, is considering whether to allow “Unlicensed National Information Infrastructure” (UNII) devices (that provide short-range, high-speed, unlicensed wireless connections for, among other applications, Wi-Fi-enabled radio local area networks, cordless telephones, and fixed outdoor broadband transceivers used by wireless Internet service providers) to operate in the same frequencies of the spectrum as V2V.

Opening any spectrum band to sharing could result in many more devices transmitting and receiving information on the same or similar frequencies. Depending on the technology, band, and uses at issue, such sharing can work well or can lead to harmful interference among those devices. Recognizing the scarcity of spectrum, in December 2015 and January 2016, the DOT, FCC, and the Department of Commerce sent joint letters to members of the U.S. Senate Committee on Commerce, Science, and Transportation, stating a shared “commitment to finding the best method to develop, successfully test, and deploy advanced automotive safety systems while working to meet existing and future spectrum demands," and announcing an interagency, multi-phased testing regime that will be used to "provide reliable, real-world data on the performance of unlicensed devices that are designed to avoid interfering with DSRC operation in the 5.9 GHz band."[149] The results of this test will inform FCC on potential sharing solutions, if any, between proposed Unlicensed National Information Infrastructure (U-NII) devices and DSRC operations in the 5.850-5.925 GHz (U-NII-4) band.

The results of the interagency tests will also be utilized to inform NHTSA's proceeding as it progresses towards afinal rulemaking on V2V. As noted in the joint DOT-FCC-Commerce letter that responds to a Congressional letter dated September 9, 2015, it is "imperative – to ensure the future automotive safety and efficiency of the traveling public – that all three phases of the FCC test plan be completed before reaching any conclusions as to whether [non-DSRC] unlicensed devices can safely operate in the 5.9 GHz band." without interfering with DSRC operation.

DOT believes that any estimate of the opportunity cost of this NPRM should be made in the context of the FCC's existing policies and authorities. Put another way, in identifying and valuing other opportunities that might be precluded or degraded by this NPRM, DOT is considering those opportunities consistent with the FCC's designation of spectrum. However, in assessing the benefits in the context of the current FCC designation on which this rule focuses, we invite and will consider comments on opportunity costs associated with broader uses of spectrum beyond the current FCC designation."

In addition, we provide a further discussion of other potential benefits of DSRC beyond the two safety applications quantified in the economic analysis for this NPRM. Those additional benefits include potential safety, congestion, environmental, UAS and Smart City benefits.

Benefits of DSRC

We first provide a further explanation of the potential additional safety benefits of DSRC beyond the two intersection safety applications quantified in the economic analysis for this NPRM.

[149] Cite to letter.

The primary benefit of the proposed rule is improved automobile safety. Chapter V of the PRIA discusses this benefit at length. DOT also wishes to present a broader discussion of the benefits not measured in the Primary Regulatory Impact Analysis and seek comment on the resulting estimate. To arrive at this estimate, we have taken existing research that quantified motor vehicle crashes as costing society over $242 billion in economic impacts in 2010 and caused societal harm of over $836 billion through fatalities, injuries and property damage.[150] Adjusting the societal harm estimate to reflect the increase in traffic fatalities and CPI in 2015, we arrive at a value of $966 billion. Recognizing previous research has indicated that V2V could potentially avoid or mitigate 80 percent of unimpaired crashes, we have conservatively calculated scenarios where V2V is phased in linearly, reaching maximum crash reduction benefits of 5, 10, and 15 percent by 2035.

Table VII-22
Summary of Estimated Present Value of Benefits of V2V communication for this NPRM Based on the Societal Harm from Crashes

Societal Harm ($M)	Percentage of crashes prevented	2018 PV at 3% discount rate ($M)	2018 PV at 7% discount rate ($M)
$966,000	5.0%	$603,620	$288,480
$966,000	10.0%	$1,207,230	$576,950
$966,000	15.0%	$1,810,850	$865,430

M: Million

A more conservative approach to calculating total benefit of the rule could be considering a function of the number of lives that would be saved by V2V communication, multiplied by the economic value of a life. A number of values have been used for the economic value of a life;, we compute our sensitivity analysis using values of $5.4 - $13.4 million (2018 value). Table VII-23 below presents different estimates for the 2018 value of the benefit of the rule through 2050.

[150] Blincoe, L, Miller, T, Zaloshnja, E., Lawrence, B., The Economic and Societal Impact of Motor Vehicle Crashes, 2010 (Revised) May, 2015 DOT HS 802 013 https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812013

Table VII-23
Summary of Estimated Present Value of Benefits of V2V communication for this NPRM
Based on the Number of Lives Saved

Value of a life (2018 $M)	Percentage of fatalities prevented	fatalities prevented	2018 PV at 3% discount rate ($M)	2018 PV at 7% discount rate ($M)
$ 5.4	1.0%	350.92	$ 38,636	$ 23,965
$ 13.4	1.0%	350.92	$ 95,874	$ 59,468
$ 5.4	5.0%	1754.6	$ 193,181	$ 119,824
$ 13.4	5.0%	1754.6	$ 479,373	$ 297,341
$ 5.4	10.0%	3509.2	$ 386,360	$ 239,648
$ 13.4	10.0%	3509.2	$ 958,747	$ 594,683

M: Million

Other Benefits of DSRC Communication

The benefits shown above offset the costs, including opportunity costs, of this proposed rule. Moreover, the beneficial uses of spectrum for vehicle-to-vehicle communications could well increase in the future. Over the last five years, the USDOT has sponsored the Connected Vehicle Program under Intelligent Transportation Systems Research. This program has identified more than fifty potential connected vehicle applications concepts, many of which have already been prototyped and demonstrated. As a part of this process, the component application development programs have also conducted assessments to measure safety, mobility, and environmental impacts. Field demonstrations have been supplemented by estimation of difficult-to-observe impacts and potential future impacts from broader application deployment using a range of analytical methods. The USDOT has published documentation from the more advanced application development efforts, including concepts of operations, system requirements, design documents, algorithms, functional descriptions, characterization test results, field test evaluation results and estimation of benefits associated with these prototypes. In total, the USDOT has identified fifty-three connected vehicle applications that will depend on effective vehicle communication. These fifty-three applications include thirteen safety applications that address vehicle occupant and pedestrian safety through communication with other vehicles as well as roadside infrastructure. They also include fifteen applications that address environmental quality and resource consumption, and many more that address congestion, mobility, and data gathering.

Opportunity Costs of Precluding Alternative Uses

Decisions regarding whether to allow additional uses of spectrum than those currently authorized by the FCC for the ITS band are not within the scope of DOT's or NHTSA's authority. Comments on the value of these uses will, however, be accepted. Such comments should consider that the interagency spectrum sharing tests are not yet complete, and it will be impossible to fully measure such benefits until the feasibility of sharing is determined. If such sharing is possible, those benefits will likely decrease opportunity costs associated with mandating V2V communications. Nothing in this rulemaking would preclude the FCC, in conjunction with DOT and NTIA, from authorizing appropriate sharing at some future date.

The chart below is a generic calculation of the spectrum opportunity cost, based on preclusion of alternative uses for the spectrum. This estimate might overstate the value of opportunity cost if sharing is determined to be possible. We use estimated Wi-Fi values from 2013 and earlier reports to estimate the economic value of one MHz of spectrum. To do this, we begin by extracting data from the largest and most recent study of spectrum values from TAS, making several adjustments based on our analysis.[151] To calculate a net present value as of 2016, we treat the annual economic value of the spectrum beginning in 2018 and until 2050, meaning that it will generate the same value for each year in the future. There are two assumptions implicit in this approach: (1) The spectrum continues to generate value into the future and (2) the value of the spectrum does not change from year to year (i.e., the growth rate is zero).[152]

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[151] Assessment of the Economic Value of Unlicensed Spectrum in the United States, Final Report, February 2014, Telecom Advisory Services, LLC http://www.wififorward.org/wp-content/uploads/2014/01/Value-of-Unlicensed-Spectrum-to-the-US-Economy-Full-Report.pdf. We first remove RFID retail because it is a very different technology from Wi-Fi and it operates at very low frequency bands (13.56, 4.33, and 902-928 MHz (i.e., all operate at less than 1 GHz). Second, Table C includes $34.885B of producer surplus associated with Wi-Fi only tablets estimated as the difference between the retail price and manufacturing costs for a weighted average of tablet suppliers. In practice, consumers pay above manufacturing costs for marketing, brand, and other amenities, making this an overestimate. As a rough adjustment, we cut this number in half to $17.44B. Adding all spectrum values from Table C of the TAS report except for RFID retail yields a total value for unlicensed Wi-Fi spectrum of $110 billion. Based on the CEA report, there are a total of 638 MHz of spectrum available for unlicensed Wi-Fi use. This includes 83 MHz in the 2.4 GHz band and 555 MHz in the 5.1-5.8 GHz band. Dividing the TAS estimate of Wi-Fi value by the total bandwidth gives an estimate of $172.4 million per each MHz of spectrum.

[152] Other researchers including Bazelon and McHenry (2015) use a similar approach. Bazelon and McHentry (2015) paper is available here:
http://www.brattle.com/system/publications/pdfs/000/005/168/original/Mobile_Broadband_Spectrum_-_A_Valuable_Resource_for_the_American_Economy_Bazelon_McHenry_051115.pdf

The estimated present value of each additional MHz up to 2050 ranges between $1.9 billion and $3.4 billion based on whether a 7 or a 3 percent discount rate is used, respectively.[153]

We seek comment on whether these per-MHz figures are reasonable, including comment on the detailed analysis in footnote 3, as well as any alternative methodologies.

Table VII-24
Summary of Estimated Present Value of Spectrum

Approach	Value (Billions of $)	MHz	Billions of $/MHz	PV to 2050, 2018 Implementation, 3% discount rate (Billions of $/MHz)	PV to 2050, 2018 Implementation, 7% discount rate (Billions of $/MHz)
Estimated Value of Wi-Fi	110	638	0.2	3.4	1.9

Other ways to estimate the opportunity cost of spectrum may be feasible, including using auction values for spectrum licenses. A method like this would require estimates of the ratio between auction value and annual consumer surplus. A method like that would generate far higher values than the table above because it uses licensed rather than unlicensed spectrum as a benchmark – making it yield an estimate that cannot be directly used to assess the value of unlicensed spectrum. Other considerations when using the estimates above to value the spectrum in question include:

1. The value of spectrum is highly situational and the historic spectrum value might not be a valid indication of the spectrum of the future. Spectrum value differs with respect to variables including, but not limited to, frequencies, size of the block or segment, international harmonization, geographic location, the timing of the release of new batches of spectrum, and the extent to which use is shared or exclusive. Frequencies might be the

[153] We use 3 and 7 percent discount rates to be consistent with OMB guidelines, available here (Step 7, p. 11): https://www.whitehouse.gov/sites/default/files/omb/inforeg/regpol/circular-a-4_regulatory-impact-analysis-a-primer.pdf

most significant factor to determine the value since different frequencies have different characteristics that make useful for different applications. The most useful bands of frequencies may be auctioned out and developed early. The spectrum values for these frequencies may have very different characteristics from the 5.9 GHz band and their value may exceed the value of the 5.9 GHz.

2. The cost of delivering information over spectrum varies and is a function of the range in which it operates. Higher frequency spectrums like 5.9 GHz broadcast over much shorter distances than lower frequency spectrums and thus require the interaction of interoperable devices over these short distances to transmit and receive messages in order for applications to activate.
3. Existing market values do not reflect the progressive increase of the economic value of spectrum over time (i.e., time-dependent value).

The above estimates yield per-MHz figures for the gross opportunity cost that would result if spectrum in these bands were monopolized. However, the actual opportunity cost associated with spectrum that would result from mandating V2V in the way prescribed in this NPRM is represented by foregone alternative uses of that spectrum, which would be more limited.
It is possible that all spectrum within the relevant 75 MHz will ultimately be used for vehicle-to-vehicle communications given the substantial safety benefits of that technology. It is, however, likely that not all spectrum within the relevant 75 MHz will be *de facto* or *de jure* used exclusively for the specific safety applications envisioned by this rule, i.e., those based on transmission of the Basic Safety Message. In particular, we propose to require BSM transmissions on a single 10 MHz channel. Multiplying this 10 MHz by the per-MHz values derived above yields an opportunity cost of $19-$34 billion. We seek comment on the best framework to appropriately consider the opportunity costs of this proposed rule across the band, taking into account varying assumptions about spectrum usage. DOT expects to include an estimate of the opportunity cost of spectrum as part of its RIA in a final rule.

<u>Increased Litigation Costs</u>

The agency recognizes the possibility of higher litigation costs due to the intraoperative nature of the V2V environment. However, the agency reiterates that driving tasks are drivers' responsibilities. The at-fault driver in a crash will bear the economic burden and this will not be altered in the V2V environment. Furthermore, V2V technology is expected to avoid crashes and thus reduce the overall burden imposed on legal systems and traffic courts.

CHAPTER VIII. BREAKEVEN ANALYSIS

A breakeven analysis is used to determine when the proposed rule will recoup all the investment up to that year through the benefits. In essence, this analysis determines the year that the total investment of the proposed rule will be paid back through the total realized benefits of the proposed rule. The total investment of the proposed rule for a year is the cumulative annual costs from the first year of implementation up to that year. Similarly, the total realized benefits would be the cumulative monetized annual benefits from the first year of implementation up to that year. All annual costs and monetized benefits used in this analysis are discounted back to 2021, the first year of implementation of the proposed rule.

The discounted cumulative monetized annual benefits at year i thus would be the sum of the discounted annual benefits from the base year up to year i and can be noted as:

$$dCB_i = \sum_{j=2021}^{i} AB_j * d_{j-2021+1}$$

Where, i = calendar year

dCB_i = discounted cumulative monetized annual benefits

AB_j = monetized annual benefits at year j

$d_{j-2021+1}$= the raw discount factor corresponds to age j-2021+1.

The discounted cumulative annual costs can be noted as:

$$dCF_i = \sum_{j=2021}^{i} F_j * d_{j-2021+1}$$

Where, dCF_i = discounted cumulative annual costs

F_j = annual costs at year j

$d_{j-2021+1}$= the raw discount factor corresponds to age j-2021+1.

Therefore, the breakeven year is the first year i that dCB_i will be equal or greater than dCF_i, i.e.,

$$\sum_{j=2021}^{i} AB_j * d_{j-2021+1} - \sum_{j=2021}^{i} F_j * d_{j-2021+1} \geq 0, \text{ or}$$

$$\sum_{j=2021}^{i} (AB_j - F_j) * d_{j-2021+1} \geq 0$$

As shown in the above formula, the breakeven year i can be interpreted as the first year when the proposed rule would achieve a positive cumulative annual net benefit (i.e., $\sum AB_j - F_j$). As discussed in the costs and benefits chapters, the magnitude of the estimated costs does not directly link to the size of the benefits, i.e., low costs do not necessarily correspond to low benefits and high costs do not necessarily correspond to high benefits. As a result, the net benefits would range from the difference between the low benefits and the high costs to the difference between the high benefits and the low costs. Table VIII-1 shows the process of deriving undiscounted annual net benefits (i.e., $AB_i - F_i$). As shown, undiscounted, the proposed rule would accrue a positive annual benefit around 2027.

Table VIII-1

Annual Net Benefits

(**Undiscounted**, 2014 $ in **Millions)**

Year	Calendar Year	Total Monetized Benefits		Annual Costs		Annual Net Benefits	
		Low	High	Low	High	Low	High
1	2021	$0	$0	$2,192	$2,864	-$2,864	-$2,192
2	2022	$19	$25	$3,011	$3,926	-$3,907	-$2,986
3	2023	$126	$165	$3,832	$4,946	-$4,820	-$3,668
4	2024	$495	$647	$3,741	$4,981	-$4,486	-$3,095
5	2025	$1,256	$1,644	$3,701	$4,803	-$3,547	-$2,057
6	2026	$2,655	$3,483	$3,655	$4,735	-$2,080	-$173
7	2027	$4,784	$6,295	$3,640	$4,705	$79	$2,655
8	2028	$7,381	$9,741	$3,634	$4,690	$2,692	$6,106
9	2029	$10,245	$13,554	$3,622	$4,668	$5,577	$9,931
10	2030	$13,336	$17,678	$3,649	$4,692	$8,643	$14,029
11	2031	$16,595	$22,041	$3,659	$4,699	$11,896	$18,381
12	2032	$19,960	$26,553	$3,662	$4,699	$15,261	$22,891
13	2033	$23,369	$31,136	$3,665	$4,699	$18,670	$27,471
14	2034	$26,770	$35,718	$3,682	$4,719	$22,051	$32,036
15	2035	$30,098	$40,212	$3,717	$4,757	$25,341	$36,495
16	2036	$33,279	$44,518	$3,713	$4,731	$28,548	$40,805
17	2037	$36,263	$48,567	$3,734	$4,726	$31,537	$44,833
18	2038	$39,002	$52,292	$3,749	$4,736	$34,266	$48,543
19	2039	$41,438	$55,616	$3,769	$4,858	$36,580	$51,847
20	2040	$43,570	$58,537	$3,831	$4,844	$38,726	$54,706

21	2041	$45,392	$61,042	$3,856	$4,872	$40,519	$57,186
22	2042	$46,898	$63,122	$3,737	$4,715	$42,183	$59,385
23	2043	$48,152	$64,860	$3,744	$4,719	$43,434	$61,116
24	2044	$49,192	$66,304	$3,752	$4,723	$44,469	$62,552
25	2045	$50,045	$67,490	$3,796	$4,764	$45,281	$63,695
26	2046	$50,768	$68,494	$3,770	$4,736	$46,032	$64,724
27	2047	$51,403	$69,374	$3,780	$4,745	$46,658	$65,594
28	2048	$51,963	$70,147	$3,789	$4,752	$47,211	$66,359
29	2049	$52,466	$70,840	$3,797	$4,759	$47,707	$67,043
30	2050	$52,911	$71,453	$3,858	$4,818	$48,093	$67,595
31	2051	$53,279	$71,960	$3,822	$4,761	$48,518	$68,138
32	2052	$53,603	$72,408	$3,813	$4,732	$48,870	$68,594
33	2053	$53,869	$72,777	$3,805	$4,719	$49,150	$68,972
34	2054	$54,096	$73,092	$3,797	$4,810	$49,285	$69,295
35	2055	$54,285	$73,356	$3,832	$4,766	$49,520	$69,523
36	2056	$54,445	$73,578	$3,782	$4,711	$49,734	$69,795
37	2057	$54,561	$73,741	$3,775	$4,700	$49,862	$69,966
38	2058	$54,624	$73,832	$3,768	$4,688	$49,936	$70,064
39	2059	$54,665	$73,894	$3,761	$4,677	$49,987	$70,133
40	2060	$54,685	$73,926	$3,804	$4,717	$49,968	$70,122

Applying appropriate raw discount factors to the costs and benefits shown above (or directly to the net benefits) and following the process specified in the above formula, we derived the cumulative annual net benefits. Tables VIII-2 and VIII-3 show the discounted cumulative annual benefits, cumulative annual costs, cumulative annual net benefits, and breakeven year at a 3 and 7 percent rate, respectively. As shown, the proposed rule would be expected to break even between 2029 and 2031 for a 3 percent discount rate and 2030 to 2032 for a 7 percent discount rate. Table VIII-4 summarizes the breakeven year results.

Table VIII-2
Breakeven Analysis
(@3 Percent Discount, 2014 $ in Millions**)**

	Calendar	Cumulative Monetized Benefits		Total Cumulative Annual Costs		Cumulative Net Benefits		Breakeven Year	
Year	Year	Low	High	Low	High	Low	High	Low	High
1	2021	$0	$0	$2,160	$2,822	-$2,822	-$2,160	*	*
2	2022	$18	$24	$5,040	$6,578	-$6,559	-$5,016	*	*
3	2023	$135	$177	$8,600	$11,172	-$11,036	-$8,423	*	*
4	2024	$581	$760	$11,973	$15,663	-$15,081	-$11,213	*	*
5	2025	$1,681	$2,199	$15,213	$19,868	-$18,186	-$13,014	*	*
6	2026	$3,938	$5,160	$18,320	$23,892	-$19,954	-$13,161	*	*
7	2027	$7,886	$10,354	$21,324	$27,775	-$19,889	-$10,970	*	*
8	2028	$13,800	$18,158	$24,236	$31,533	-$17,732	-$6,078	*	*
9	2029	$21,769	$28,700	$27,053	$35,164	-$13,395	$1,647	*	2029
10	2030	$31,840	$42,050	$29,809	$38,707	-$6,867	$12,241	*	2030
11	2031	$44,007	$58,211	$32,492	$42,152	$1,855	$25,719	2031	2031
12	2032	$58,215	$77,111	$35,099	$45,497	$12,718	$42,013	2032	2032
13	2033	$74,365	$98,630	$37,632	$48,744	$25,621	$60,998	2033	2033
14	2034	$92,328	$122,597	$40,102	$51,911	$40,417	$82,494	2034	2034
15	2035	$111,934	$148,791	$42,524	$55,009	$56,925	$106,267	2035	2035
16	2036	$132,980	$176,944	$44,872	$58,001	$74,979	$132,072	2036	2036
17	2037	$155,245	$206,764	$47,165	$60,903	$94,342	$159,599	2037	2037
18	2038	$178,494	$237,935	$49,400	$63,726	$114,768	$188,536	2038	2038
19	2039	$202,478	$270,126	$51,581	$66,537	$135,941	$218,545	2039	2039
20	2040	$226,960	$303,018	$53,734	$69,259	$157,701	$249,284	2040	2040
21	2041	$251,726	$336,322	$55,837	$71,918	$179,808	$280,485	2041	2041
22	2042	$276,568	$369,758	$57,817	$74,415	$202,153	$311,941	2042	2042
23	2043	$301,328	$403,109	$59,742	$76,841	$224,486	$343,367	2043	2043
24	2044	$325,889	$436,214	$61,616	$79,200	$246,690	$374,599	2044	2044
25	2045	$350,146	$468,927	$63,455	$81,509	$268,637	$405,472	2045	2045
26	2046	$374,038	$501,160	$65,229	$83,738	$290,300	$435,931	2046	2046
27	2047	$397,524	$532,857	$66,956	$85,906	$311,618	$465,901	2047	2047
28	2048	$420,574	$563,975	$68,637	$88,014	$332,561	$495,337	2048	2048
29	2049	$443,171	$594,486	$70,273	$90,063	$353,108	$524,213	2049	2049
30	2050	$465,294	$624,360	$71,886	$92,078	$373,216	$552,474	2050	2050
31	2051	$486,919	$653,569	$73,437	$94,010	$392,909	$580,132	2051	2051
32	2052	$508,044	$682,104	$74,940	$95,875	$412,169	$607,165	2052	2052
33	2053	$528,654	$709,949	$76,396	$97,681	$430,974	$633,553	2053	2053
34	2054	$548,751	$737,102	$77,806	$99,468	$449,283	$659,296	2054	2054
35	2055	$568,332	$763,562	$79,189	$101,187	$467,145	$684,373	2055	2055
36	2056	$587,399	$789,329	$80,513	$102,837	$484,562	$708,816	2056	2056
37	2057	$605,949	$814,401	$81,797	$104,435	$501,515	$732,604	2057	2057
38	2058	$623,981	$838,772	$83,040	$105,982	$517,999	$755,732	2058	2058
39	2059	$641,501	$862,455	$84,246	$107,481	$534,020	$778,210	2059	2059
40	2060	$658,513	$885,454	$85,429	$108,949	$549,565	$800,025	2060	2060

*not breakeven

Table VIII-3
Breakeven Analysis
(@7 Percent Discount, 2014 $ in **Millions)**

Year	Calendar Year	Cumulative Monetized Benefits Low	Cumulative Monetized Benefits High	Total Cumulative Annual Costs Low	Total Cumulative Annual Costs High	Cumulative Net Benefits Low	Cumulative Net Benefits High	Breakeven Year Low	Breakeven Year High
1	2021	$0	$0	$2,119	$2,768	-$2,768	-$2,119	*	*
2	2022	$17	$23	$4,840	$6,316	-$6,299	-$4,817	*	*
3	2023	$124	$162	$8,076	$10,492	-$10,369	-$7,914	*	*
4	2024	$514	$672	$11,028	$14,423	-$13,909	-$10,356	*	*
5	2025	$1,441	$1,884	$13,757	$17,965	-$16,524	-$11,873	*	*
6	2026	$3,271	$4,285	$16,277	$21,228	-$17,958	-$11,992	*	*
7	2027	$6,353	$8,340	$18,622	$24,260	-$17,907	-$10,282	*	*
8	2028	$10,796	$14,204	$20,810	$27,083	-$16,287	-$6,606	*	*
9	2029	$16,560	$21,829	$22,847	$29,709	-$13,149	-$1,018	*	*
10	2030	$23,572	$31,124	$24,766	$32,176	-$8,604	$6,358	*	2030
11	2031	$31,727	$41,955	$26,564	$34,485	-$2,759	$15,391	*	2031
12	2032	$40,894	$54,151	$28,246	$36,643	$4,251	$25,905	2032	2032
13	2033	$50,925	$67,515	$29,819	$38,660	$12,264	$37,695	2033	2033
14	2034	$61,665	$81,845	$31,297	$40,554	$21,111	$50,548	2034	2034
15	2035	$72,949	$96,920	$32,690	$42,337	$30,612	$64,230	2035	2035
16	2036	$84,610	$112,520	$33,991	$43,995	$40,615	$78,528	2036	2036
17	2037	$96,486	$128,425	$35,214	$45,542	$50,943	$93,211	2037	2037
18	2038	$108,420	$144,426	$36,361	$46,992	$61,429	$108,065	2038	2038
19	2039	$120,271	$160,333	$37,439	$48,381	$71,891	$122,893	2039	2039
20	2040	$131,918	$175,980	$38,463	$49,676	$82,242	$137,516	2040	2040
21	2041	$143,257	$191,228	$39,427	$50,893	$92,364	$151,801	2041	2041
22	2042	$154,207	$205,967	$40,299	$51,994	$102,214	$165,668	2042	2042
23	2043	$164,714	$220,119	$41,116	$53,023	$111,691	$179,003	2043	2043
24	2044	$174,744	$233,639	$41,881	$53,986	$120,758	$191,757	2044	2044
25	2045	$184,283	$246,502	$42,605	$54,894	$129,388	$203,898	2045	2045
26	2046	$193,325	$258,701	$43,276	$55,738	$137,587	$215,425	2046	2046
27	2047	$201,883	$270,252	$43,905	$56,528	$145,355	$226,346	2047	2047
28	2048	$209,969	$281,167	$44,495	$57,267	$152,701	$236,672	2048	2048
29	2049	$217,597	$291,467	$45,047	$57,959	$159,638	$246,420	2049	2049
30	2050	$224,788	$301,177	$45,571	$58,614	$166,174	$255,606	2050	2050
31	2051	$231,554	$310,316	$46,057	$59,219	$172,336	$264,260	2051	2051
32	2052	$237,917	$318,911	$46,509	$59,780	$178,136	$272,402	2052	2052
33	2053	$243,891	$326,982	$46,931	$60,304	$183,587	$280,051	2053	2053
34	2054	$249,501	$334,562	$47,325	$60,803	$188,698	$287,236	2054	2054
35	2055	$254,761	$341,670	$47,697	$61,264	$193,497	$293,973	2055	2055
36	2056	$259,688	$348,329	$48,039	$61,691	$197,997	$300,290	2056	2056
37	2057	$264,304	$354,567	$48,358	$62,088	$202,216	$306,209	2057	2057
38	2058	$268,625	$360,407	$48,656	$62,459	$206,166	$311,751	2058	2058
39	2059	$272,665	$365,868	$48,934	$62,805	$209,860	$316,934	2059	2059
40	2060	$276,443	$370,976	$49,197	$63,131	$213,313	$321,779	2060	2060

*not breakeven

Table VIII-4
Summary of the Breakeven Year of the Proposed Rule

Discount Rate	Year
At 3 Percent	2029 to 2031
At 7 Percent	2030 to 2032

CHAPTER IX. COST-EFFECTIVENESS AND MY NET-BENEFITS

The cost-effectiveness analysis examines the MY vehicles that would be cost-effective. A MY vehicle would be cost-effective if its net cost per fatal equivalent is no greater than the $9.7 million comprehensive cost of a fatality. The net cost in this PRIA is defined as the difference between the MY costs and the MY congestion benefits and PDO savings (i.e., the lifetime savings of these two categories for a MY vehicle). From an owner's/societal perspective, the analysis shows that as an owner, you are paying for this new technology when you buy the vehicle and you are paying for additional fuel and possibly communication costs over the lifetime of the vehicle. At the same time from the societal perspective, your risk of being in a crash is being increasingly reduced over time as more and more vehicles have DSRC with which you can communicate. Monetized benefits will exceed costs at some point. This analysis shows for which model year the lifetime benefits to society (and statistically to you) after discounting exceed the costs.

The net-benefit analysis determines the MY vehicles that would generate positive net benefits over the lifespan of the vehicles (i.e., MY net benefits). The MY net benefits as defined are equal to the difference between the monetized MY benefits and the corresponding MY costs. The monetized MY benefits that were derived in the Monetized Benefits chapter and the costs from the Costs chapter are used in these two analyses.

A. Cost-Effectiveness Analysis

The net cost per equivalent life saved is used to determine the cost-effectiveness for MY vehicles. The net cost defined in this analysis is the difference between the MY costs and the savings from reducing property damage and congestion. As described earlier, fatal equivalents were derived by translating MAIS 1-5 injuries saved and PDOVs prevented into fatalities using their relative fatality ratios. (Note that the Monetized Benefits chapter discussed this process and thus this chapter does not repeat it.)

Tables IX-1 and IX-2 present the cost-effectiveness process and the net cost per fatal equivalent discounted at 3 percent and 7 percent, respectively. As shown in the tables, MY 2024 to MY 2026 vehicles would become cost-effective for both discount rates. Note that the negative MY net cost shown in the tables means that the MY benefits outweigh its costs.

For each discount rate, the range of fatal equivalents covers those from the two MY benefit estimating approaches discussed previously in the Benefit chapter: free-rider and no free-rider. The low fatal equivalent numbers represent the low benefit estimates from the free-rider approach and the high numbers represent the high benefit estimates from the no free-rider approach. The low and high benefits respond to the low and high effectiveness of the apps, respectively.

Furthermore, as discussed in the Costs chapter, the range of the costs represents the two cost estimates from the two technology implementation approaches. The low costs represent the costs for the one-DSRC radio approach. The high costs represent the costs for the two-DSRC radio approach.[154]

[154] The one-DSRC radio consists of one DSRC radio in vehicle paring with a hybrid (WiFi/Cellular/Satellite) vehicle-to-SCMS communication. The two DSRC radios in vehicle are paring with DSRC vehicle-to-SCMS communication.

Table IX-1
Cost-Effectiveness Analysis by Model Year Vehicles
(@3 Percent Discount, 2014 $ in **Millions**)

Year	Model Year	Fatal Equivalents		MY Net Costs		Net Cost per Fatal Equivalent		Cost-Effective	
		Low	High	Low	High	Low	High	Low	High
1	2021	0.00	0.00	$2,221.39	$2,893.52	$2,221.39	$2,893.52	*	*
2	2022	3.48	67.86	$2,958.11	$3,963.34	$43.59	$1,138.99	*	*
3	2023	23.35	208.55	$3,592.36	$4,965.74	$17.23	$212.68	*	*
4	2024	104.31	580.04	$2,975.53	$4,884.16	$5.13	$46.82	2024	*
5	2025	257.57	1,017.05	$2,317.96	$4,491.28	$2.28	$17.44	2025	*
6	2026	586.69	1,774.90	$1,208.85	$3,970.64	$0.68	$6.77	2026	2026
7	2027	1,112.42	2,621.45	$7.03	$3,221.61	$0.00	$2.90	2027	2027
8	2028	1,606.16	3,090.78	-$657.77	$2,530.40	-$0.21	$1.58	2028	2028
9	2029	1,946.18	3,250.93	-$896.40	$2,042.34	-$0.28	$1.05	2029	2029
10	2030	2,252.45	3,415.26	-$1,101.36	$1,645.84	-$0.32	$0.73	2030	2030
11	2031	2,523.52	3,563.63	-$1,301.00	$1,280.31	-$0.37	$0.51	2031	2031
12	2032	2,761.74	3,697.69	-$1,487.91	$952.38	-$0.40	$0.34	2032	2032
13	2033	2,847.78	3,975.69	-$1,876.58	$833.11	-$0.47	$0.29	2033	2033
14	2034	2,934.41	4,241.63	-$2,233.79	$731.05	-$0.53	$0.25	2034	2034
15	2035	3,009.61	4,475.08	-$2,526.26	$664.36	-$0.56	$0.22	2035	2035
16	2036	3,074.84	4,678.59	-$2,816.23	$547.13	-$0.60	$0.18	2036	2036
17	2037	3,134.46	4,858.86	-$3,048.91	$459.30	-$0.63	$0.15	2037	2037
18	2038	3,182.03	5,007.07	-$3,242.04	$402.76	-$0.65	$0.13	2038	2038
19	2039	3,224.93	5,139.68	-$3,409.01	$463.44	-$0.66	$0.14	2039	2039
20	2040	3,269.38	5,267.60	-$3,527.55	$387.12	-$0.67	$0.12	2040	2040
21	2041	3,320.90	5,404.46	-$3,692.67	$345.44	-$0.68	$0.10	2041	2041
22	2042	3,224.76	5,283.11	-$3,646.00	$315.00	-$0.69	$0.10	2042	2042
23	2043	3,241.75	5,334.51	-$3,711.27	$294.44	-$0.70	$0.09	2043	2043
24	2044	3,258.96	5,380.31	-$3,768.41	$274.41	-$0.70	$0.08	2044	2044
25	2045	3,275.27	5,423.17	-$3,785.48	$292.50	-$0.70	$0.09	2045	2045
26	2046	3,290.63	5,461.25	-$3,865.08	$242.56	-$0.71	$0.07	2046	2046
27	2047	3,306.52	5,499.93	-$3,909.53	$228.66	-$0.71	$0.07	2047	2047
28	2048	3,319.75	5,536.44	-$3,952.52	$216.58	-$0.71	$0.07	2048	2048
29	2049	3,333.27	5,571.05	-$3,992.64	$204.60	-$0.72	$0.06	2049	2049
30	2050	3,350.10	5,608.31	-$3,984.67	$240.58	-$0.71	$0.07	2050	2050

* The proposed rule would not be cost effective for the MY vehicles since the net cost per fatal equivalent is greater than $9.7M in 2014 dollars.

Table IX-2
Cost-Effectiveness Analysis by Model Year Vehicles
(**@7 Percent Discount**, 2014 $ in **Millions**)

Year	Model Year	Fatal Equivalents		MY Net Costs		Net Cost per Fatal Equivalent		Cost-Effective	
		Low	High	Low	High	Low	High	Low	High
1	2021	0.00	0.00	$2,213.68	$2,885.80	$2,213.68	$2,885.80	*	*
2	2022	3.28	51.18	$2,969.81	$3,952.00	$58.02	$1,206.56	*	*
3	2023	21.83	159.55	$3,645.47	$4,952.42	$22.85	$226.83	*	*
4	2024	96.35	450.18	$3,141.76	$4,879.71	$6.98	$50.64	2024	*
5	2025	234.85	795.52	$2,612.54	$4,507.19	$3.28	$19.19	2025	*
6	2026	527.59	1,396.62	$1,722.09	$4,035.73	$1.23	$7.65	2026	2026
7	2027	989.03	2,077.54	$751.28	$3,373.91	$0.36	$3.41	2027	2027
8	2028	1,416.94	2,459.15	$208.58	$2,771.96	$0.08	$1.96	2028	2028
9	2029	1,710.25	2,598.90	-$2.00	$2,347.17	$0.00	$1.37	2029	2029
10	2030	1,974.86	2,741.45	-$177.05	$2,006.97	-$0.06	$1.02	2030	2030
11	2031	2,149.18	2,947.24	-$458.15	$1,772.63	-$0.16	$0.82	2031	2031
12	2032	2,233.37	3,227.88	-$850.33	$1,654.44	-$0.26	$0.74	2032	2032
13	2033	2,309.61	3,478.57	-$1,200.35	$1,548.14	-$0.35	$0.67	2033	2033
14	2034	2,385.57	3,711.72	-$1,512.27	$1,460.19	-$0.41	$0.61	2034	2034
15	2035	2,451.89	3,916.19	-$1,764.75	$1,405.16	-$0.45	$0.57	2035	2035
16	2036	2,509.12	4,095.07	-$2,020.80	$1,298.41	-$0.49	$0.52	2036	2036
17	2037	2,562.08	4,254.99	-$2,225.59	$1,219.23	-$0.52	$0.48	2037	2037
18	2038	2,602.73	4,384.79	-$2,393.47	$1,171.68	-$0.55	$0.45	2038	2038
19	2039	2,640.12	4,501.23	-$2,538.36	$1,239.43	-$0.56	$0.47	2039	2039
20	2040	2,678.06	4,613.37	-$2,635.41	$1,171.48	-$0.57	$0.44	2040	2040
21	2041	2,720.95	4,730.53	-$2,773.58	$1,141.05	-$0.59	$0.42	2041	2041
22	2042	2,641.60	4,624.69	-$2,748.24	$1,088.07	-$0.59	$0.41	2042	2042
23	2043	2,656.70	4,670.32	-$2,805.80	$1,069.77	-$0.60	$0.40	2043	2043
24	2044	2,670.51	4,709.04	-$2,853.41	$1,054.05	-$0.61	$0.39	2044	2044
25	2045	2,685.53	4,747.17	-$2,864.22	$1,073.57	-$0.60	$0.40	2045	2045
26	2046	2,696.56	4,779.45	-$2,936.06	$1,029.21	-$0.61	$0.38	2046	2046
27	2047	2,711.29	4,815.03	-$2,976.53	$1,016.55	-$0.62	$0.37	2047	2047
28	2048	2,721.94	4,845.29	-$3,011.12	$1,007.69	-$0.62	$0.37	2048	2048
29	2049	2,734.33	4,873.87	-$3,043.14	$996.93	-$0.62	$0.36	2049	2049
30	2050	2,747.06	4,905.91	-$3,028.20	$1,038.18	-$0.62	$0.38	2050	2050

* The proposed rule would not be cost effective for the MY vehicles since the net cost per fatal equivalent is greater than $9.7M in 2014 dollars

B. Lifetime Net Benefits for a MY Vehicles

The lifetime net benefits for a MY vehicles (i.e., MY net benefits) are the difference between the monetized MY benefits and the corresponding MY costs. Tables IX-3 and IX-4 show the MY net benefits at a 3 and 7 percent discount rate, respectively. As shown, for both discount rates, MY 2024 to MY 2026 vehicles would begin to accrue positive lifetime net benefits. (Due to rounding errors, discrepancy existed between the monetized MY benefits that were derived directly by multiplying $9.7 million by fatal equivalents and those reported in the tables below.) Finally, Table IX-5 summarizes the MY vehicles that would be cost-effective.

Table IX-3
MY Net Benefits
(**@3 Percent Discount**, 2014 $ in **Millions**)

Year	Model Year	Monetized MY Benefits		MY Costs		MY Net Benefits	
		Low	High	Low	High	Low	High
1	2021	$0.00	$0.00	$2,221.39	$2,893.52	-$2,893.52	-$2,221.39
2	2022	$33.79	$658.99	$3,053.02	$3,968.08	-$3,934.29	-$2,394.03
3	2023	$226.72	$2,025.12	$3,884.01	$4,997.52	-$4,770.80	-$1,858.89
4	2024	$1,012.92	$5,632.53	$3,786.63	$5,026.18	-$4,013.26	$1,845.90
5	2025	$2,501.20	$9,876.22	$3,740.01	$4,842.01	-$2,340.81	$6,136.21
6	2026	$5,697.12	$17,235.41	$3,690.23	$4,769.58	$927.54	$13,545.18
7	2027	$10,802.30	$25,455.98	$3,671.47	$4,736.63	$6,065.67	$21,784.52
8	2028	$15,596.91	$30,013.55	$3,662.23	$4,718.02	$10,878.89	$26,351.32
9	2029	$18,898.69	$31,568.66	$3,646.96	$4,693.24	$14,205.45	$27,921.70
10	2030	$21,872.79	$33,164.45	$3,671.21	$4,714.08	$17,158.71	$29,493.24
11	2031	$24,505.02	$34,605.22	$3,678.46	$4,717.95	$19,787.07	$30,926.76
12	2032	$26,818.31	$35,906.98	$3,678.43	$4,714.96	$22,103.36	$32,228.55
13	2033	$27,653.77	$38,606.57	$3,678.63	$4,713.02	$22,940.75	$34,927.94
14	2034	$28,495.06	$41,189.00	$3,692.47	$4,729.11	$23,765.95	$37,496.53
15	2035	$29,225.26	$43,456.01	$3,725.64	$4,764.99	$24,460.27	$39,730.37
16	2036	$29,858.67	$45,432.21	$3,719.46	$4,736.74	$25,121.92	$41,712.75
17	2037	$30,437.71	$47,182.69	$3,738.10	$4,730.26	$25,707.44	$43,444.60
18	2038	$30,899.56	$48,621.96	$3,751.52	$4,738.62	$26,160.94	$44,870.43
19	2039	$31,316.16	$49,909.68	$3,769.32	$4,857.85	$26,458.31	$46,140.36
20	2040	$31,747.87	$51,151.88	$3,829.01	$4,842.19	$26,905.68	$47,322.87
21	2041	$32,248.10	$52,480.81	$3,854.63	$4,870.78	$27,377.32	$48,626.18
22	2042	$31,314.49	$51,302.48	$3,731.52	$4,709.39	$26,605.10	$47,570.96
23	2043	$31,479.52	$51,801.61	$3,737.75	$4,712.04	$26,767.49	$48,063.86
24	2044	$31,646.62	$52,246.36	$3,744.33	$4,715.51	$26,931.12	$48,502.03
25	2045	$31,805.05	$52,662.57	$3,786.93	$4,755.86	$27,049.18	$48,875.65
26	2046	$31,954.16	$53,032.36	$3,760.35	$4,726.88	$27,227.28	$49,272.01
27	2047	$32,108.44	$53,407.94	$3,769.78	$4,734.65	$27,373.79	$49,638.16
28	2048	$32,236.99	$53,762.45	$3,777.66	$4,740.64	$27,496.35	$49,984.79
29	2049	$32,368.22	$54,098.58	$3,785.78	$4,747.09	$27,621.14	$50,312.80
30	2050	$32,531.65	$54,460.39	$3,845.70	$4,806.01	$27,725.64	$50,614.69

Table IX-4
MY Net Benefits
(**@7 Percent Discount**, 2014 $ in **Millions**)

Year	Model Year	Monetized MY Benefits Low	Monetized MY Benefits High	Vehicle Costs Low	Vehicle Costs High	MY Net Benefits Low	MY Net Benefits High
1	2021	$0.00	$0.00	$2,213.68	$2,885.80	-$2,885.80	-$2,213.68
2	2022	$31.80	$497.03	$3,041.41	$3,956.46	-$3,924.66	-$2,544.37
3	2023	$212.00	$1,549.29	$3,868.62	$4,982.14	-$4,770.14	-$2,319.34
4	2024	$935.65	$4,371.50	$3,771.35	$5,010.90	-$4,075.25	$600.15
5	2025	$2,280.53	$7,725.00	$3,724.97	$4,826.97	-$2,546.44	$4,000.03
6	2026	$5,123.26	$13,562.13	$3,674.84	$4,754.19	$369.08	$9,887.29
7	2027	$9,604.09	$20,174.30	$3,655.69	$4,720.85	$4,883.24	$16,518.61
8	2028	$13,759.41	$23,879.93	$3,646.03	$4,701.83	$9,057.59	$20,233.89
9	2029	$16,607.61	$25,236.98	$3,630.38	$4,676.66	$11,930.95	$21,606.59
10	2030	$19,177.23	$26,621.24	$3,654.18	$4,697.04	$14,480.18	$22,967.06
11	2031	$20,869.91	$28,619.59	$3,661.00	$4,700.48	$16,169.42	$24,958.59
12	2032	$21,687.48	$31,344.84	$3,660.57	$4,697.09	$16,990.38	$27,684.27
13	2033	$22,427.83	$33,779.21	$3,660.38	$4,694.77	$17,733.06	$30,118.83
14	2034	$23,165.40	$36,043.23	$3,673.77	$4,710.41	$18,455.00	$32,369.46
15	2035	$23,809.50	$38,028.75	$3,706.49	$4,745.84	$19,063.67	$34,322.26
16	2036	$24,365.23	$39,765.77	$3,699.88	$4,717.16	$19,648.07	$36,065.89
17	2037	$24,879.46	$41,318.79	$3,718.05	$4,710.22	$20,169.24	$37,600.74
18	2038	$25,274.25	$42,579.22	$3,731.05	$4,718.15	$20,556.11	$38,848.18
19	2039	$25,637.28	$43,709.92	$3,748.39	$4,836.91	$20,800.36	$39,961.54
20	2040	$26,005.75	$44,798.85	$3,807.57	$4,820.75	$21,185.00	$40,991.28
21	2041	$26,422.20	$45,936.55	$3,832.67	$4,848.82	$21,573.37	$42,103.88
22	2042	$25,651.68	$44,908.74	$3,709.90	$4,687.77	$20,963.91	$41,198.84
23	2043	$25,798.30	$45,351.86	$3,715.80	$4,690.09	$21,108.20	$41,636.06
24	2044	$25,932.43	$45,727.85	$3,722.05	$4,693.23	$21,239.19	$42,005.80
25	2045	$26,078.29	$46,098.16	$3,764.31	$4,733.25	$21,345.04	$42,333.85
26	2046	$26,185.33	$46,411.61	$3,737.41	$4,703.94	$21,481.39	$42,674.20
27	2047	$26,328.44	$46,757.14	$3,746.51	$4,711.38	$21,617.06	$43,010.63
28	2048	$26,431.78	$47,050.95	$3,754.07	$4,717.05	$21,714.73	$43,296.87
29	2049	$26,552.13	$47,328.48	$3,761.88	$4,723.19	$21,828.94	$43,566.60
30	2050	$26,675.71	$47,639.58	$3,821.49	$4,781.80	$21,893.91	$43,818.10

Table IX-5
Summary of the MY That Would Be Cost-Effective and Have Positive Net Benefits

Discount Rate	Cost-Effective	Positive Net Benefits
At 3 Percent	2024 to 2026	2024 to 2026
At 7 Percent	2024 to 2026	2024 to 2026

CHAPTER X. REGULATORY ALTERNATIVES

Typically, in analyzing alternatives, an agency looks to alternatives that are more or less stringent, or more or less design-oriented, than the proposal. Often times, particularly for NHTSA rules, this involves analysis of alternative technological solutions or stringency levels (e.g., a crash test at a higher or lower speed than the proposal). For regulatory alternatives, the agency has focused on different ways V2V and safety applications could be mandated. Alternative 1 would mandate both V2V communications and also require the installation of apps, which is more stringent than the proposed rule.[155] Alternative 2 is less stringent than the propose rule because it would not mandate DSRC and instead allow for a free market approach for V2V adoption; this alternative is also referred to as the "If-Equipped" alternative. The following lists these two alternatives:

- Alternative 1: Mandating DSRC/V2V and Apps
- Alternative 2: If-equipped rulemaking that would allow DSRC communication with requirements as specified in the proposed rule.

The agency believes that these two alternatives represent a significant range of potential agency actions when compared to the proposal. Of these alternatives, because of mandating both DSRC/V2V and apps, Alternative 1 would ensure the deployment of apps and thus can guarantee achieving the anticipated benefits. Alternative 2, on the other hand, faces much greater uncertainty regarding the adoption of V2V than does the proposed rule.

The agency decided not to select Alternative 1, primarily due to the consideration of the time needed for testing apps' performance. In contrast to the vehicle-resident safety systems that rely exclusively on the data from its own sensors and vehicle performance, the V2V-based apps require inputs from nearby vehicles or roadway equipment. The V2V safety apps therefore

[155] The concept of stringency is difficult for this rulemaking because V2V either works successfully or it does not. For example, the agency also considered mandating fewer pieces of data within the BSM, but that would have only marginal (if any) difference in cost, while leading to considerably less safety. Similar reasoning applies to the proposed requirements concerning security. Likewise, the agency has requested comment on a phase-in schedule and compliance dates, but does not believe that differences here are sufficient to be considered alternatives. Thus, although the agency is requesting comment on all aspects of the proposal, the BSM, security, and timing, these are not regulatory alternatives that can be readily analyzed.

would need to accommodate the BSM from all the on-road operational models. Although, the agency is proposing a standardized BSM, certain data elements would be allowed to have a specified variation. These apps would need to consider the variabilities of the incoming messages to ensure that they would perform at the designed. Therefore, the agency believes allowing a free-market approach for apps development is the preferred approach for considering these challenges. Furthermore, since the costs for the DSRC onboard unit (OBU) will be "sunk" because of the mandate, the incremental cost to offer the application software will be extremely low. Since the manufactures would have already incurred the majority of the cost, the agency is confident that the manufacturers will fully explore introducing safety applications without the need for a mandate. The agency believes that the manufacturers will most likely to make the small incremental investment in the application software so that their products can compete in the marketplace relative to safety performance. Any manufacturers not offering the safety applications would be dis-advantaged in the marketplace. For these reasons, Alternative 1 was not chosen.

The decision of not selecting Alternative 2 was based on the estimated costs of V2V and the interoperable nature of the V2V communication. The agency believes that Alternative 2 is unlikely to lead to meaningful deployment of V2V and would delay potentially for a significant period of time the anticipated benefits of V2V. The agency also believes that significant delay about using the designated spectrum for V2V safety applications when the technology is ready for deployment could lead to intensified claims to re-designate the spectrum in ways beyond those currently contemplated in joint Test Plan for spectrum sharing. The greater uncertainty on the anticipated benefits, the wider disparity on benefits between early and later adopters, and the disproportional costs to benefit ratio made the Alternative 2 (see the subsequent seconds on the cost and benefit results) not a viable choice. The following sections describe these two regulatory alternatives and the cost and benefit estimates of these alternatives.

A. Alternative 1 – Mandate Both DSRC and Apps

Alternative 1 would mandate both DSRC radios and the two apps (IMA and LTA). For DSRC, this alternative would require a 50%-75%-100% three-year phase-in, same as the proposed rule, while for safety apps, there would be a 4 years phase-in of 0%-50%-75%-100%, which is the primary difference between this alternative and the proposed rule. The one year delay for apps allows manufacturers the time to perform necessary tests and adjustments since these apps would be required to accommodate message inputs from diverse vehicle models and production lines. The consideration of the variability of the incoming message creates unique challenges for testing and deployment. Figure X-1 depicts the app adoption rates for Alternative 1 and the proposed rule. The process of estimating the benefits and costs of the alternative follows the process discussed in the Benefits and Costs chapters. Therefore, this chapter shows the estimated results only and does not repeat the process.

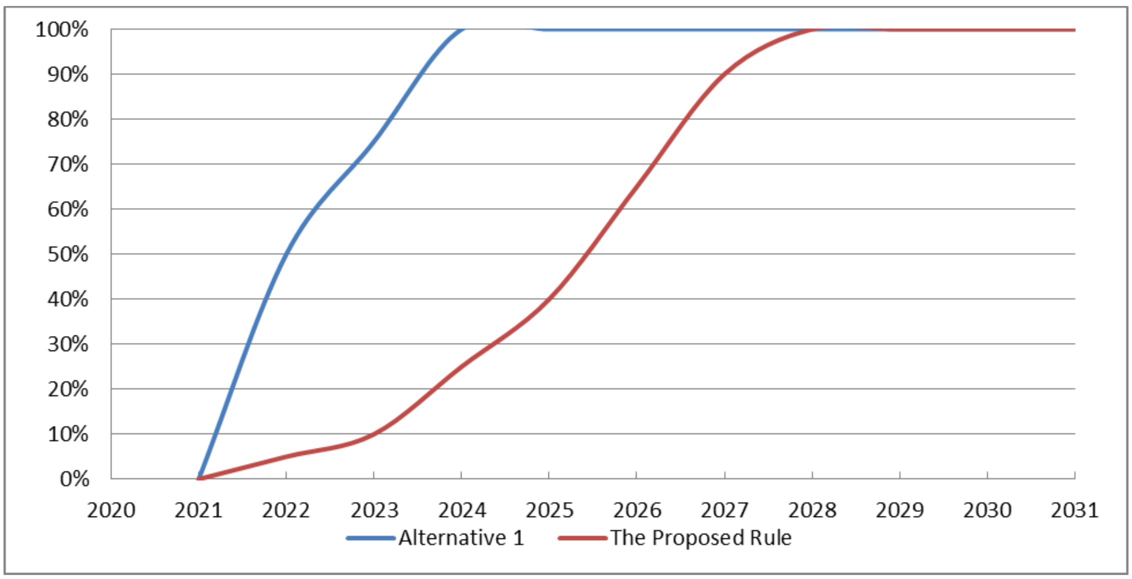


Figure X-1
Safety Apps Adoption Rates for Alternative 1 and the Proposed Rule

Since this alternative has a more aggressive app adoption schedule, the alternative would accrue more annual benefits than the benefits that the proposed rule would accrue for years leading to the full adoption of DSRC and apps. At full adoption, the maximum annual benefits for this alternative are identical to those of the proposed rule. However, this alternative would reach the maximum level four years sooner when compared to the proposed rule. Furthermore, the incremental costs of adding apps over DSRC radios are relatively small (less than 0.1 percent of the cost of DSRC radios). The costs for this alternative thus would not be significantly different from those for the proposed rule. Since the benefits would increase faster than the costs, the alternative would reach the breakeven year between 2027 and 2030, two years sooner than the proposed rule. In addition, the alternative would be cost-effective and accrue positive net benefits between MY 2022 and 2024, also two MYs ahead of the proposed rule. Table X-1 compares the breakeven year and the MY vehicles that would be cost-effective and accrue positive net benefits of this alternative to those of the proposed rule.

Table X-1
Comparison of Breakeven and Cost-Effectiveness Measures
Between Alternative 1 and the Proposed Rule

	Alternative 1	**The Proposed Rule**
Breakeven Year (CY)	2027 to 2030	2029 to 2032
Cost-Effective Year (MY)	2022 to 2024	2024 to 2026
Positive Net Benefits Year (MY)	2022 to 2024	2024 to 2026

Although mandating the V2V communication technology and V2V-based apps would result in significant safety benefits, the agency is not mandating these apps with this NPRM since the agency believes that additional research is needed. Specifically, we believe that the research for establishing test procedures and performance of the apps has not been conducted. Without the crucial research, mandating apps might lead to unintended consequences (such as unacceptable numbers of false alarms) which would have negative effects on the development and deployment of V2V-based apps. We request comments on the research needed for mandating the apps.

Moreover, the proposed rule mandating only the V2V communication technology with specified performance requirements and message transmitting protocol allows for the implementation of interoperable V2V communication devices. This removes the biggest obstacle from the deployment of V2V-based apps and thus encourages a free-market approach for apps and fosters app innovation. The low cost of implementation of apps gives us confidence that manufacturers could realistically undertake to develop such applications and begin deploying them in the field once DSRC is mandated. Therefore, the agency decided not to select this alternative.

The following details the benefit and cost estimates, breakeven, cost-effective, and net-benefit measures of the alternative.

A.1 Benefits

As described in the Benefits chapter, the V2V benefits would be influenced by the communication rates. The communication rate depends on the number of vehicles that would have the V2V technology. Table X-2 presents the on-road vehicles that would have only the DSRC radios without the apps and those would have the apps and the DSRC radios. The number of on-road light vehicles with the V2V technology was calculated based on the technology adoption scenario for this alternative. Table X-3 shows the corresponding communication rates.

Table X-2
On-Road Light Vehicles Would Have the V2V Technology
Alternative 1 - Mandate DSRC and Apps
(in Millions)

		Total on-Road Vehicles Would Have DSRC			Total on-Road Vehicles Would Have Apps		
Year	Calendar Year	PCs	LTVs	Combined	PCs	LTVs	Combined
1	2021	4.13	3.97	8.10	0.00	0.00	0.00
2	2022	10.32	9.89	20.21	3.12	3.00	6.13
3	2023	18.58	17.76	36.34	9.37	8.98	18.35
4	2024	26.78	25.51	52.28	17.69	16.90	34.59
5	2025	34.92	33.21	68.13	25.97	24.74	50.71
6	2026	42.97	40.82	83.79	34.16	32.49	66.66
7	2027	50.94	48.35	99.29	42.30	40.18	82.47
8	2028	58.84	55.77	114.61	50.36	47.79	98.16
9	2029	66.60	63.03	129.64	58.33	55.28	113.61
10	2030	74.24	70.09	144.33	66.19	62.65	128.84
11	2031	81.66	76.85	158.51	73.91	69.82	143.73
12	2032	88.80	83.25	172.05	81.43	76.68	158.10
13	2033	95.61	89.28	184.89	88.66	83.16	171.83
14	2034	102.08	94.94	197.02	95.60	89.31	184.90
15	2035	108.15	100.25	208.39	102.18	95.08	197.26
16	2036	113.79	105.20	218.98	108.37	100.49	208.86
17	2037	118.93	109.84	228.78	114.14	105.55	219.69
18	2038	123.53	114.16	237.70	119.41	110.28	229.68
19	2039	127.56	118.18	245.73	124.13	114.70	238.83
20	2040	131.06	121.90	252.96	128.30	118.82	247.12
21	2041	134.12	125.37	259.49	131.97	122.67	254.64
22	2042	136.11	128.46	264.57	134.46	126.13	260.59
23	2043	137.75	131.29	269.04	136.49	129.26	265.76
24	2044	139.12	133.89	273.00	138.15	132.13	270.28
25	2045	140.28	136.32	276.60	139.54	134.76	274.30
26	2046	141.31	138.61	279.92	140.73	137.20	277.93
27	2047	142.23	140.81	283.04	141.76	139.51	281.27
28	2048	143.05	142.93	285.97	142.67	141.72	284.39
29	2049	143.80	144.93	288.73	143.49	143.83	287.33

30	2050	144.50	146.84	291.34	144.25	145.85	290.10
31	2051	145.03	148.61	293.64	144.90	147.71	292.61
32	2052	145.45	150.24	295.69	145.40	149.42	294.83
33	2053	145.78	151.73	297.51	145.78	151.00	296.78
34	2054	146.07	153.08	299.15	146.07	152.44	298.51
35	2055	146.32	154.27	300.60	146.32	153.74	300.06
36	2056	146.54	155.32	301.86	146.54	154.90	301.44
37	2057	146.73	156.22	302.96	146.73	155.90	302.63
38	2058	146.91	156.91	303.82	146.91	156.76	303.66
39	2059	147.07	157.48	304.54	147.07	157.42	304.49
40	2060	147.22	157.93	305.15	147.22	157.93	305.15

Table X-3

Light Vehicle Fleet Communication Rates

Alternative 1 - Mandate DSRC and Apps

	Calendar	IMA			LTA		
Year	Year	PCs	LTVs	Combined	PCs	LTVs	Combined
1	2021	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
2	2022	0.18%	0.17%	0.35%	0.11%	0.10%	0.21%
3	2023	0.85%	0.81%	1.66%	0.57%	0.54%	1.11%
4	2024	2.03%	1.94%	3.97%	1.52%	1.45%	2.97%
5	2025	3.60%	3.43%	7.03%	2.86%	2.73%	5.59%
6	2026	5.50%	5.23%	10.73%	4.56%	4.34%	8.90%
7	2027	7.70%	7.32%	15.02%	6.59%	6.26%	12.85%
8	2028	10.18%	9.66%	19.84%	8.90%	8.45%	17.35%
9	2029	12.89%	12.21%	25.10%	11.47%	10.87%	22.34%
10	2030	15.78%	14.94%	30.72%	14.26%	13.49%	27.75%
11	2031	18.81%	17.77%	36.58%	17.21%	16.26%	33.47%
12	2032	21.92%	20.64%	42.56%	20.28%	19.09%	39.37%
13	2033	25.04%	23.49%	48.53%	23.39%	21.94%	45.33%
14	2034	28.13%	26.28%	54.41%	26.50%	24.76%	51.26%
15	2035	31.14%	28.97%	60.11%	29.56%	27.50%	57.06%
16	2036	33.99%	31.52%	65.51%	32.49%	30.13%	62.62%
17	2037	36.64%	33.88%	70.52%	35.24%	32.59%	67.83%
18	2038	39.02%	36.04%	75.06%	37.75%	34.86%	72.61%
19	2039	41.08%	37.95%	79.03%	39.95%	36.92%	76.87%
20	2040	42.81%	39.65%	82.46%	41.84%	38.75%	80.59%
21	2041	44.22%	41.11%	85.33%	43.41%	40.35%	83.76%
22	2042	45.24%	42.44%	87.68%	44.57%	41.81%	86.38%
23	2043	46.02%	43.58%	89.60%	45.47%	43.06%	88.53%
24	2044	46.62%	44.58%	91.20%	46.16%	44.14%	90.30%
25	2045	47.07%	45.46%	92.53%	46.68%	45.08%	91.76%
26	2046	47.42%	46.23%	93.65%	47.08%	45.90%	92.98%
27	2047	47.71%	46.96%	94.67%	47.42%	46.66%	94.08%
28	2048	47.96%	47.64%	95.60%	47.69%	47.38%	95.07%
29	2049	48.16%	48.27%	96.43%	47.93%	48.04%	95.97%
30	2050	48.32%	48.86%	97.18%	48.12%	48.65%	96.77%
31	2051	48.43%	49.37%	97.80%	48.26%	49.19%	97.45%

32	2052	48.49%	49.83%	98.32%	48.35%	49.69%	98.04%
33	2053	48.51%	50.25%	98.76%	48.39%	50.13%	98.52%
34	2054	48.51%	50.63%	99.14%	48.41%	50.52%	98.93%
35	2055	48.49%	50.95%	99.44%	48.40%	50.86%	99.26%
36	2056	48.46%	51.23%	99.69%	48.40%	51.15%	99.55%
37	2057	48.43%	51.45%	99.88%	48.37%	51.40%	99.77%
38	2058	48.36%	51.60%	99.96%	48.33%	51.57%	99.90%
39	2059	48.30%	51.70%	100.00%	48.29%	51.69%	99.98%
40	2060	48.25%	51.75%	100.00%	48.25%	51.75%	100.00%

A.1.1 Maximum Annual Benefits

The maximum annual benefits for the alternative are identical to those estimated for the proposed rule since the maximum benefits represent the benefits that would be realized when all on-road light vehicles have the DSRC radios and the two apps. It is the timeframe for achieving the maximum annual benefits set this alternative apart from the proposed rule. Since the alternative requires 100 percent app adoption on Year 4 as opposed to Year 8 as estimated for the proposed rule, the alternative would achieve the maximum benefits four years sooner when compared to the proposed rule.

A.1.2 Annual Benefits

Because of its aggressive app adoption schedule when compared to the proposed rule, the alternative would accrue a higher amount of estimated annual benefits than the proposed rule until the year that 100 percent of on-road light vehicles have DSRC and the apps. Table X-4 shows the annual benefits of the alternative.

Table X-4
Annual Benefits
Alternative 1, Mandate DSRC and Apps

(Undiscounted)

	Calendar	Crash Prevented		Fatalities Eliminated		MAIS 1-5 Injuries		PDOVs	
Year	Year	Low	High	Low	High	Low	High	Low	High
1	2021	0	0	0	0	0	0	0	0
2	2022	1,387	1,897	3	4	955	1,270	1,714	2,331
3	2023	6,699	9,204	15	21	4,622	6,178	8,264	11,286
4	2024	16,362	22,592	37	51	11,308	15,208	20,135	27,624
5	2025	29,331	40,614	66	91	20,291	27,383	36,045	49,580
6	2026	45,166	62,666	102	140	31,267	42,300	55,450	76,412
7	2027	63,646	88,440	144	198	44,083	59,750	78,081	107,749
8	2028	84,476	117,512	191	262	58,533	79,440	103,581	143,081
9	2029	107,294	149,384	242	333	74,365	101,036	131,502	181,798
10	2030	131,758	183,581	297	409	91,344	124,218	161,426	223,322
11	2031	157,352	219,384	355	489	109,112	148,498	192,722	266,778
12	2032	183,537	256,035	414	570	127,295	173,362	224,732	311,249
13	2033	209,755	292,754	472	652	145,503	198,279	256,772	355,787
14	2034	235,641	329,029	531	732	163,485	222,904	288,399	399,773
15	2035	260,791	364,288	587	811	180,958	246,845	319,118	442,516
16	2036	284,688	397,812	641	885	197,564	269,615	348,297	483,140
17	2037	306,914	429,009	691	954	213,012	290,812	375,430	520,934
18	2038	327,119	457,387	736	1017	227,058	310,101	400,087	555,300
19	2039	344,873	482,349	776	1072	239,405	327,077	421,742	585,512
20	2040	360,255	503,989	810	1120	250,105	341,799	440,499	611,694
21	2041	373,188	522,201	839	1160	259,104	354,196	456,260	633,716
22	2042	383,803	537,158	863	1193	266,492	364,380	469,195	651,798
23	2043	392,487	549,396	882	1220	272,536	372,714	479,774	666,589
24	2044	399,700	559,554	898	1243	277,555	379,629	488,564	678,872
25	2045	405,683	567,977	912	1261	281,718	385,361	495,858	689,059
26	2046	410,711	575,053	923	1277	285,216	390,176	501,988	697,619
27	2047	415,279	581,476	933	1291	288,392	394,545	507,559	705,392
28	2048	419,429	587,309	942	1304	291,278	398,511	512,622	712,454
29	2049	423,151	592,545	951	1316	293,867	402,073	517,161	718,789
30	2050	426,500	597,253	958	1326	296,196	405,274	521,246	724,487
31	2051	429,289	601,178	965	1335	298,136	407,946	524,645	729,235
32	2052	431,649	604,506	970	1342	299,779	410,213	527,520	733,256
33	2053	433,625	607,288	974	1348	301,154	412,105	529,929	736,621
34	2054	435,327	609,681	978	1354	302,338	413,734	532,004	739,517
35	2055	436,678	611,582	981	1358	303,277	415,028	533,650	741,816
36	2056	437,819	613,194	984	1361	304,072	416,126	535,040	743,762
37	2057	438,686	614,418	986	1364	304,676	416,961	536,095	745,241
38	2058	439,092	615,003	986	1365	304,961	417,364	536,584	745,938
39	2059	439,310	615,322	987	1366	305,115	417,586	536,845	746,317
40	2060	439,332	615,359	987	1366	305,131	417,613	536,869	746,357

A.1.3 MY Benefits

Tables X-5 and X-6 show the MY benefits for the alternative, discounted at 3 percent and 7 percent. As described in the Benefits chapter, these benefits represent the combined benefits from the free-rider and no free rider approaches. The free-rider approach credited a lower amount of benefits to early MY vehicles when compared to the no free-ride approach. As a result, the free-rider approach resulted in a lower amount of MY benefits when compared to the no free-rider approach. In the tables below, the low benefits are from the free-rider approach and the high benefits are from the no free-rider approach.

Table X-5
MY Benefits of Alternative 1**, Mandate DSRC and Apps**

@3 Percent Discount

	Model	Crash Prevented		Fatalities Eliminated		MAIS 1-5 Injuries		PDOVs	
Year	Year	Low	High	Low	High	Low	High	Low	High
1	2021	0	0	0	0	0	0	0	0
2	2022	17,162	23,852	39	53	11,888	16,116	21,052	29,057
3	2023	39,130	54,431	88	122	27,112	36,795	47,981	66,276
4	2024	58,407	81,319	132	181	40,481	55,000	71,584	98,964
5	2025	64,559	89,950	146	201	44,757	60,863	79,096	109,423
6	2026	70,338	98,064	159	219	48,774	66,378	86,150	119,251
7	2027	76,200	106,295	172	237	52,849	71,970	93,305	129,220
8	2028	81,940	114,355	185	255	56,839	77,448	100,311	138,983
9	2029	87,158	121,687	196	271	60,467	82,433	106,677	147,860
10	2030	92,402	129,057	208	287	64,113	87,444	113,074	156,781
11	2031	97,269	135,900	219	302	67,498	92,098	119,010	165,063
12	2032	101,671	142,095	229	316	70,560	96,313	124,378	172,557
13	2033	105,660	147,711	238	328	73,336	100,135	129,241	179,349
14	2034	109,551	153,188	246	341	76,043	103,863	133,982	185,973
15	2035	112,956	157,986	254	351	78,413	107,130	138,131	191,773
16	2036	116,063	162,366	261	361	80,576	110,114	141,917	197,067
17	2037	118,847	166,292	267	369	82,514	112,788	145,307	201,811
18	2038	121,117	169,497	272	377	84,095	114,973	148,071	205,681
19	2039	123,116	172,320	277	383	85,487	116,897	150,504	209,089
20	2040	125,271	175,358	282	389	86,987	118,967	153,128	212,761
21	2041	127,615	178,658	287	397	88,618	121,212	155,985	216,751
22	2042	120,360	168,516	270	374	83,582	114,337	147,112	204,437
23	2043	121,214	169,722	272	377	84,177	115,159	148,150	205,892
24	2044	121,787	170,533	274	379	84,577	115,713	148,847	206,871
25	2045	122,490	171,525	275	381	85,066	116,389	149,703	208,069
26	2046	123,071	172,344	277	383	85,470	116,947	150,410	209,058
27	2047	123,661	173,176	278	384	85,881	117,514	151,129	210,064
28	2048	123,998	173,653	279	386	86,116	117,839	151,539	210,639

29	2049	124,471	174,319	280	387	86,445	118,293	152,114	211,444
30	2050	124,939	174,979	281	388	86,771	118,742	152,685	212,242

Table X-6
MY Benefits of Alternative 1, **Mandate DSRC and Apps**
@7 Percent Discount

	Model	Crash Prevented		Fatalities Eliminated		MAIS 1-5 Injuries		PDOVs	
Year	Year	Low	High	Low	High	Low	High	Low	High
1	2021	0	0	0	0	0	0	0	0
2	2022	17,870	29	40	8,911	12,068	15,793	21,780	29,057
3	2023	41,520	67	93	20,692	28,055	36,641	50,577	66,276
4	2024	62,611	102	140	31,181	42,332	55,166	76,223	98,964
5	2025	70,001	113	156	34,842	47,352	61,600	85,179	109,423
6	2026	76,882	124	171	38,249	52,027	67,584	93,515	119,251
7	2027	83,875	136	187	41,712	56,779	73,665	101,986	129,220
8	2028	90,771	147	202	45,126	61,465	79,661	110,339	138,983
9	2029	97,183	157	216	48,299	65,824	85,230	118,103	147,860
10	2030	103,511	167	230	51,431	70,126	90,725	125,765	156,781
11	2031	109,479	176	244	54,383	74,184	95,903	132,988	165,063
12	2032	114,874	185	256	57,050	77,854	100,579	139,515	172,557
13	2033	119,770	193	266	59,470	81,186	104,819	145,437	179,349
14	2034	124,575	200	277	61,845	84,457	108,981	151,250	185,973
15	2035	128,895	207	287	63,979	87,397	112,718	156,472	191,773
16	2036	132,622	213	295	65,819	89,936	115,937	160,976	197,067
17	2037	136,151	219	303	67,562	92,340	118,987	165,241	201,811
18	2038	138,905	223	309	68,920	94,217	121,360	168,566	205,681
19	2039	141,411	227	314	70,156	95,926	123,520	171,591	209,089
20	2040	144,029	231	320	71,448	97,709	125,780	174,754	212,761
21	2041	146,833	236	326	72,834	99,618	128,207	178,144	216,751
22	2042	138,594	222	308	68,743	94,033	120,996	168,140	204,437
23	2043	139,543	224	310	69,210	94,681	121,812	169,284	205,892
24	2044	140,334	225	312	69,600	95,221	122,492	170,239	206,871
25	2045	141,149	227	313	70,002	95,776	123,195	171,223	208,069
26	2046	141,927	228	315	70,387	96,306	123,867	172,164	209,058
27	2047	142,558	229	317	70,698	96,736	124,411	172,925	210,064
28	2048	142,993	229	317	70,912	97,033	124,786	173,450	210,639
29	2049	143,599	230	319	71,212	97,445	125,310	174,183	211,444
30	2050	144,058	231	320	71,438	97,758	125,706	174,738	212,242

A.2 Monetized Benefits

A.2.1. Monetized Maximum Annual Benefits

Based on the process described previously, to derive the monetized value the benefits (i.e., eliminated injuries and PDOVs), benefits were first translated into fatal equivalents and then multiplying the fatal equivalents by the value of a fatality. Alternative 1 would save 5,634 to 7,617 fatal equivalents and $54.7 to $74.0 billion annually. Of the monetized savings, $7.7 to $10.6 billion are from reducing crash related congestion and property damaged vehicles, $2.1 to $2.9 billion are congestion savings and $5.6 to $7.7 billion are from property damaged vehicles. These benefits are identical to those of the proposed rule since the maximum benefits represent the benefit level when all on-road light vehicles have the DSRC radios and the apps IMA and LTA. However, Due to a relatively more aggressive app adoption, Alternative 1 would achieve these maximum annual benefits four years earlier than the proposed rule. Readers can also refer back to Table VI-2 for these maximum annual benefit statistics.

A.2.2. Monetized Annual Benefits

Table X-7 presents the undiscounted monetized annual benefits for Alternative 1. This alternative would save 18 to 23 fatal equivalents and a total of $172.6 to $226.7 million in 2022. Of these savings, $24.2 to $32.7 million is from the reduction of property damage vehicles and crash related congestion. These benefits are approximately 9 times of those of the proposed rule. The difference reflects the difference in the app adoption rates between the alternative (50 percent) and the proposed rule (5 percent). In 2060, when all vehicles have the DSRC radios and the two safety apps, the alternative would save approximately 5,634 to 7,617 fatal equivalents annually. The total associated monetized annual savings would range from $54.7 to $74.0 billion. Of these savings, $7.7 to $10.6 billion would be property damage and congestion savings. These benefits reached the maximum annual level.

Table X-7
Annual Monetized Benefits of Alternative 1
(**Undiscounted**, 2014 $ in Millions)

	Calendar	Fatal Equivalents		Total Monetized Benefits		Property Damage and Congestion	
Year	Year	Low	High	Low	High	Low	High
1	2021	0.00	0.00	0.00	0.00	$0.00	$0.00
2	2022	17.77	23.35	172.60	226.73	$24.20	$32.67
3	2023	85.88	113.44	833.97	1,101.53	$116.96	$158.66
4	2024	209.77	278.75	2,037.04	2,706.82	$285.73	$389.69
5	2025	376.06	501.43	3,651.79	4,869.16	$512.28	$700.81

6	2026	579.10	774.03	5,623.41	7,516.38	$788.92	$1,081.61
7	2027	816.07	1,092.77	7,924.57	10,611.50	$1,111.81	$1,526.78
8	2028	1,083.18	1,452.35	10,518.38	14,103.24	$1,475.78	$2,028.97
9	2029	1,375.77	1,846.62	13,359.67	17,931.92	$1,874.49	$2,579.57
10	2030	1,689.48	2,269.74	16,406.00	22,040.68	$2,301.98	$3,170.40
11	2031	2,017.69	2,712.80	19,593.08	26,343.03	$2,749.24	$3,789.03
12	2032	2,353.49	3,166.41	22,853.90	30,747.93	$3,206.85	$4,422.38
13	2033	2,689.70	3,620.92	26,118.70	35,161.51	$3,665.04	$5,056.93
14	2034	3,021.67	4,069.99	29,342.35	39,522.30	$4,117.46	$5,683.87
15	2035	3,344.19	4,506.54	32,474.27	43,761.43	$4,557.01	$6,293.28
16	2036	3,650.65	4,921.65	35,450.16	47,792.44	$4,974.67	$6,872.75
17	2037	3,935.69	5,308.00	38,218.09	51,544.17	$5,363.16	$7,412.04
18	2038	4,194.80	5,659.50	40,734.27	54,957.44	$5,716.32	$7,902.64
19	2039	4,422.50	5,968.76	42,945.36	57,960.58	$6,026.67	$8,334.26
20	2040	4,619.77	6,236.89	44,861.01	60,564.29	$6,295.56	$8,708.45
21	2041	4,785.63	6,462.60	46,471.64	62,756.07	$6,521.64	$9,023.41
22	2042	4,921.78	6,647.99	47,793.74	64,556.34	$6,707.23	$9,282.09
23	2043	5,033.15	6,799.68	48,875.19	66,029.35	$6,859.03	$9,493.75
24	2044	5,125.66	6,925.58	49,773.48	67,251.88	$6,985.12	$9,669.43
25	2045	5,202.39	7,029.96	50,518.65	68,265.52	$7,089.72	$9,815.09
26	2046	5,266.88	7,117.64	51,144.89	69,116.93	$7,177.62	$9,937.45
27	2047	5,325.46	7,197.23	51,713.71	69,889.77	$7,257.47	$10,048.52
28	2048	5,378.69	7,269.48	52,230.61	70,591.46	$7,330.02	$10,149.37
29	2049	5,426.43	7,334.36	52,694.14	71,221.47	$7,395.08	$10,239.91
30	2050	5,469.37	7,392.67	53,111.20	71,787.71	$7,453.62	$10,321.30
31	2051	5,505.14	7,441.32	53,458.50	72,260.10	$7,502.37	$10,389.18
32	2052	5,535.41	7,482.59	53,752.43	72,660.81	$7,543.63	$10,446.76
33	2053	5,560.75	7,517.05	53,998.55	72,995.45	$7,578.18	$10,494.85
34	2054	5,582.58	7,546.70	54,210.49	73,283.42	$7,607.93	$10,536.23
35	2055	5,599.90	7,570.26	54,378.66	73,512.22	$7,631.53	$10,569.11
36	2056	5,614.54	7,590.25	54,520.84	73,706.33	$7,651.49	$10,597.00
37	2057	5,625.66	7,605.44	54,628.83	73,853.76	$7,666.65	$10,618.18
38	2058	5,630.86	7,612.71	54,679.34	73,924.41	$7,673.75	$10,628.31
39	2059	5,633.67	7,616.70	54,706.62	73,963.19	$7,677.58	$10,633.87
40	2060	5,633.95	7,617.18	54,709.32	73,967.78	$7,677.96	$10,634.52

A.2.3 Monetized MY Benefits

Tables X-8 and X-9 present the monetized MY benefits of the alternative, discounted at 3 percent and 7 percent, respectively.

Table X-8
Monetized MY Benefits of Alternative 1
(**@3 Percent** Discount, 2014 $ in Millions)

Year	Model Year	Fatal Equivalents		Total Monetized Benefits		Property Damage and Congestion	
		Low	High	Low	High	Low	High
1	2021	0.00	0.00	$0.00	$0.00	$0.00	$0.00

2	2022	45.53	590.36	$442.16	$5,732.77	$62.02	$824.80
3	2023	267.37	1,346.65	$2,596.37	$13,076.84	$364.21	$1,881.29
4	2024	662.64	2,008.86	$6,434.69	$19,507.31	$902.75	$2,806.16
5	2025	988.88	2,221.85	$9,602.66	$21,575.58	$1,347.27	$3,103.48
6	2026	1,286.91	2,421.53	$12,496.72	$23,514.64	$1,753.39	$3,382.20
7	2027	1,569.62	2,622.87	$15,242.07	$25,469.83	$2,138.66	$3,663.24
8	2028	1,841.89	2,819.78	$17,885.92	$27,381.93	$2,509.69	$3,938.08
9	2029	2,093.33	3,001.28	$20,327.61	$29,144.35	$2,852.36	$4,191.40
10	2030	2,340.24	3,184.43	$22,725.26	$30,922.93	$3,188.86	$4,447.03
11	2031	2,486.78	3,456.98	$24,148.25	$33,569.51	$3,388.68	$4,827.79
12	2032	2,597.59	3,737.93	$25,224.34	$36,297.71	$3,539.72	$5,219.95
13	2033	2,698.53	3,992.45	$26,204.53	$38,769.33	$3,677.31	$5,575.21
14	2034	2,798.02	4,233.54	$27,170.58	$41,110.46	$3,812.91	$5,911.70
15	2035	2,886.39	4,449.90	$28,028.70	$43,211.48	$3,933.37	$6,213.66
16	2036	2,965.81	4,640.93	$28,799.95	$45,066.51	$4,041.63	$6,480.25
17	2037	3,039.50	4,817.19	$29,515.52	$46,778.09	$4,142.08	$6,726.21
18	2038	3,098.80	4,963.23	$30,091.33	$48,196.22	$4,222.91	$6,929.99
19	2039	3,153.60	5,097.71	$30,623.52	$49,502.09	$4,297.62	$7,117.63
20	2040	3,208.93	5,228.81	$31,160.81	$50,775.14	$4,373.04	$7,300.56
21	2041	3,270.94	5,369.87	$31,762.97	$52,145.00	$4,457.57	$7,497.43
22	2042	3,184.64	5,256.57	$30,924.99	$51,044.74	$4,339.98	$7,339.16
23	2043	3,208.65	5,313.04	$31,158.06	$51,593.06	$4,372.70	$7,417.94
24	2044	3,231.43	5,363.55	$31,379.29	$52,083.56	$4,403.75	$7,488.42
25	2045	3,253.66	5,410.08	$31,595.21	$52,535.40	$4,434.06	$7,553.35
26	2046	3,272.33	5,451.07	$31,776.43	$52,933.45	$4,459.50	$7,610.55
27	2047	3,291.22	5,491.50	$31,959.89	$53,326.02	$4,485.25	$7,666.96
28	2048	3,307.55	5,529.12	$32,118.44	$53,691.34	$4,507.51	$7,719.47
29	2049	3,322.76	5,564.47	$32,266.16	$54,034.62	$4,528.24	$7,768.80
30	2050	3,339.62	5,603.49	$32,429.85	$54,413.52	$4,551.22	$7,823.26

Table X-9
Monetized MY Benefits of Alternative 1
(**@7 Percent** Discount, 2014 $ in Millions)

Year	Model Year	Fatal Equivalents		Total Monetized Benefits		Property Damage and Congestion	
		Low	High	Low	High	Low	High
1	2021	0.00	0.00	$0.00	$0.00	$0.00	$0.00
2	2022	40.88	438.02	$397.01	$4,253.45	$55.68	$612.02
3	2023	235.78	1,017.41	$2,289.57	$9,879.67	$321.17	$1,421.44
4	2024	576.89	1,534.99	$5,601.98	$14,905.72	$785.91	$2,144.35
5	2025	856.99	1,716.26	$8,321.94	$16,666.00	$1,167.57	$2,397.39
6	2026	1,113.79	1,885.84	$10,815.63	$18,312.74	$1,517.51	$2,634.10
7	2027	1,357.83	2,057.31	$13,185.44	$19,977.82	$1,850.07	$2,873.45
8	2028	1,593.34	2,225.73	$15,472.40	$21,613.25	$2,171.02	$3,108.53
9	2029	1,769.28	2,438.49	$17,180.82	$23,679.34	$2,410.86	$3,405.80
10	2030	1,886.20	2,729.51	$18,316.26	$26,505.30	$2,570.23	$3,812.07
11	2031	1,993.18	2,999.97	$19,355.04	$29,131.68	$2,716.03	$4,189.62
12	2032	2,090.69	3,245.64	$20,301.93	$31,517.27	$2,848.94	$4,532.53
13	2033	2,178.14	3,469.88	$21,151.13	$33,694.76	$2,968.14	$4,845.51
14	2034	2,264.67	3,685.40	$21,991.46	$35,787.69	$3,086.10	$5,146.33
15	2035	2,343.13	3,878.07	$22,753.33	$37,658.62	$3,193.04	$5,415.22
16	2036	2,412.45	4,049.88	$23,426.50	$39,327.00	$3,287.54	$5,654.98
17	2037	2,476.63	4,205.16	$24,049.70	$40,834.83	$3,375.02	$5,871.67
18	2038	2,527.53	4,336.74	$24,543.94	$42,112.56	$3,444.40	$6,055.27
19	2039	2,575.82	4,454.99	$25,012.90	$43,260.91	$3,510.23	$6,220.27
20	2040	2,623.70	4,569.71	$25,477.86	$44,374.84	$3,575.50	$6,380.34
21	2041	2,676.12	4,692.99	$25,986.86	$45,572.02	$3,646.95	$6,552.38
22	2042	2,606.48	4,595.55	$25,310.61	$44,625.79	$3,552.06	$6,416.26
23	2043	2,627.26	4,646.68	$25,512.41	$45,122.30	$3,580.39	$6,487.60
24	2044	2,646.64	4,690.90	$25,700.61	$45,551.76	$3,606.81	$6,549.30
25	2045	2,665.16	4,731.98	$25,880.43	$45,950.65	$3,632.05	$6,606.62
26	2046	2,680.89	4,768.20	$26,033.22	$46,302.38	$3,653.50	$6,657.17
27	2047	2,696.16	4,804.78	$26,181.45	$46,657.61	$3,674.30	$6,708.22
28	2048	2,710.09	4,837.32	$26,316.78	$46,973.55	$3,693.30	$6,753.62
29	2049	2,724.68	4,866.52	$26,458.41	$47,257.12	$3,713.18	$6,794.37
30	2050	2,737.27	4,898.77	$26,580.64	$47,570.24	$3,730.34	$6,839.38

A.3 Costs

A.3.1 Annual Costs

Table X-10 presents the annual costs for the alternative. The difference in annual costs between the alternative and the proposed rule is only the app costs since costs associated with the communication, SCMS, and fuel economy impact are directly affected by the number of vehicles that would have DSRC radios, which is identical under either alternative.

The analysis shows that the first year total annual cost for the alternative is equal to that of the proposed rule since the alternative requires 0% app adoption for the first MY vehicles. After the first year, the total annual cost for the alternative is slightly higher than the annual costs for the proposed rule due to the relatively small incremental costs associated with the apps. These two total annual costs are identical for the years when the full adoption of DSRC radios and apps are reached. Note that per vehicle cost is the cost per new vehicle sold as opposed to per vehicle that would be affected by the phase-in schedule.

Table X-10
Total Annual Costs and Cost per Vehicle of Alternative 1
(2014 $)

Year	Calendar Year	Annual Costs (in **Millions**)		Annual Cost per Vehicle	
		Low	High	Low	High
1	2021	$2,191.73	$2,863.85	$135.38	$176.89
2	2022	$3,022.42	$3,937.47	$184.97	$240.97
3	2023	$3,851.45	$4,964.96	$234.27	$302.01
4	2024	$3,762.23	$5,001.78	$227.60	$302.59
5	2025	$3,718.09	$4,820.09	$223.04	$289.15
6	2026	$3,666.36	$4,745.71	$218.89	$283.33
7	2027	$3,646.16	$4,711.32	$216.00	$279.11
8	2028	$3,638.31	$4,694.10	$213.64	$275.64
9	2029	$3,626.45	$4,672.73	$211.70	$272.78
10	2030	$3,653.67	$4,696.54	$211.19	$271.48
11	2031	$3,663.92	$4,703.40	$210.09	$269.69
12	2032	$3,666.72	$4,703.25	$208.81	$267.84
13	2033	$3,669.76	$4,704.15	$207.68	$266.22
14	2034	$3,686.83	$4,723.47	$206.66	$264.77
15	2035	$3,722.18	$4,761.53	$206.79	$264.53
16	2036	$3,718.35	$4,735.63	$204.76	$260.77
17	2037	$3,738.74	$4,730.91	$203.86	$257.96
18	2038	$3,753.96	$4,741.05	$203.03	$256.41
19	2039	$3,773.96	$4,862.49	$202.25	$260.58
20	2040	$3,835.88	$4,849.05	$203.28	$256.97
21	2041	$3,861.19	$4,877.34	$201.73	$254.82
22	2042	$3,742.00	$4,719.87	$201.62	$254.30
23	2043	$3,749.38	$4,723.67	$200.93	$253.14
24	2044	$3,756.89	$4,728.07	$200.26	$252.03
25	2045	$3,800.47	$4,769.41	$201.40	$252.75
26	2046	$3,774.61	$4,741.14	$198.98	$249.93
27	2047	$3,784.91	$4,749.78	$198.37	$248.94
28	2048	$3,793.77	$4,756.75	$197.80	$248.01
29	2049	$3,802.38	$4,763.68	$197.22	$247.08
30	2050	$3,863.14	$4,823.45	$199.23	$248.76
31	2051	$3,826.60	$4,766.06	$197.35	$245.80
32	2052	$3,818.31	$4,737.22	$196.92	$244.31
33	2053	$3,810.14	$4,723.74	$196.50	$243.62
34	2054	$3,802.20	$4,815.44	$196.09	$248.35
35	2055	$3,837.33	$4,770.96	$197.90	$246.05
36	2056	$3,787.19	$4,716.22	$195.32	$243.23
37	2057	$3,779.99	$4,704.63	$194.95	$242.63
38	2058	$3,772.76	$4,693.24	$194.57	$242.04
39	2059	$3,765.67	$4,682.18	$194.21	$241.47
40	2060	$3,809.21	$4,721.92	$196.45	$243.52

A.3.2 MY Costs

Tables X-11 and X-12 show the MY costs at a 3 percent and 7 percent discount rate, respectively.

Table X-11
Total MY Costs and Cost Per Vehicle of Alternative 1
(**@3 Percent** Discount, 2014 $)

Year	Model Year	Total MY Costs (in Millions)		MY Cost per Vehicle	
		Low	High	Low	High
1	2021	$2,221.39	$2,893.52	$137.21	$178.72
2	2022	$3,064.05	$3,979.11	$187.52	$243.52
3	2023	$3,903.11	$5,016.62	$237.42	$305.15
4	2024	$3,807.72	$5,047.26	$230.35	$305.34
5	2025	$3,757.00	$4,859.00	$225.37	$291.48
6	2026	$3,701.42	$4,780.76	$220.98	$285.42
7	2027	$3,677.43	$4,742.59	$217.86	$280.96
8	2028	$3,666.37	$4,722.17	$215.29	$277.29
9	2029	$3,651.30	$4,697.58	$213.15	$274.23
10	2030	$3,675.70	$4,718.57	$212.47	$272.75
11	2031	$3,683.05	$4,722.54	$211.18	$270.79
12	2032	$3,683.09	$4,719.61	$209.74	$268.77
13	2033	$3,683.34	$4,717.73	$208.45	$266.99
14	2034	$3,697.24	$4,733.88	$207.24	$265.35
15	2035	$3,730.46	$4,769.81	$207.25	$264.99
16	2036	$3,724.32	$4,741.60	$205.08	$261.10
17	2037	$3,743.00	$4,735.17	$204.09	$258.19
18	2038	$3,756.46	$4,743.56	$203.16	$256.55
19	2039	$3,774.30	$4,862.82	$202.27	$260.60
20	2040	$3,834.04	$4,847.21	$203.18	$256.87
21	2041	$3,859.71	$4,875.87	$201.66	$254.75
22	2042	$3,736.44	$4,714.31	$201.32	$254.00
23	2043	$3,742.68	$4,716.97	$200.57	$252.79
24	2044	$3,749.28	$4,720.46	$199.85	$251.62
25	2045	$3,791.89	$4,760.83	$200.95	$252.30
26	2046	$3,765.32	$4,731.86	$198.49	$249.44
27	2047	$3,774.77	$4,739.65	$197.84	$248.41
28	2048	$3,782.67	$4,745.64	$197.22	$247.43
29	2049	$3,790.80	$4,752.11	$196.62	$246.48
30	2050	$3,850.74	$4,811.05	$198.59	$248.12

Table X-12
Total MY Costs and Cost Per Vehicle of Alternative 1
(**@7 Percent** Discount, 2014 $)

Year	Model Year	Total MY Costs (in Million)		MY Cost per Vehicle	
		Low	High	Low	High
1	2021	$2,213.68	$2,885.80	$136.73	$178.25
2	2022	$3,052.43	$3,967.49	$186.81	$242.81
3	2023	$3,887.73	$5,001.24	$236.48	$304.21
4	2024	$3,792.43	$5,031.98	$229.43	$304.42
5	2025	$3,741.96	$4,843.96	$224.47	$290.58
6	2026	$3,686.03	$4,765.37	$220.06	$284.50
7	2027	$3,661.65	$4,726.81	$216.92	$280.02
8	2028	$3,650.18	$4,705.97	$214.34	$276.33
9	2029	$3,634.72	$4,681.01	$212.18	$273.26
10	2030	$3,658.67	$4,701.53	$211.48	$271.76

11	2031	$3,665.58	$4,705.07	$210.18	$269.79
12	2032	$3,665.22	$4,701.75	$208.73	$267.75
13	2033	$3,665.09	$4,699.48	$207.42	$265.96
14	2034	$3,678.53	$4,715.17	$206.20	$264.30
15	2035	$3,711.31	$4,750.65	$206.18	$263.93
16	2036	$3,704.74	$4,722.02	$204.01	$260.02
17	2037	$3,722.95	$4,715.12	$203.00	$257.09
18	2038	$3,735.99	$4,723.08	$202.05	$255.44
19	2039	$3,753.36	$4,841.89	$201.14	$259.48
20	2040	$3,812.60	$4,825.77	$202.05	$255.74
21	2041	$3,837.75	$4,853.91	$200.51	$253.60
22	2042	$3,714.82	$4,692.69	$200.15	$252.84
23	2043	$3,720.74	$4,695.02	$199.40	$251.61
24	2044	$3,727.00	$4,698.18	$198.67	$250.44
25	2045	$3,769.28	$4,738.22	$199.75	$251.10
26	2046	$3,742.39	$4,708.92	$197.28	$248.23
27	2047	$3,751.50	$4,716.38	$196.62	$247.19
28	2048	$3,759.08	$4,722.06	$195.99	$246.20
29	2049	$3,766.91	$4,728.21	$195.38	$245.24
30	2050	$3,826.53	$4,786.84	$197.35	$246.87

A.4 Breakeven Analysis

Tables X-13 and X-14 show the breakeven year at a 3 percent and 7 percent discount rate, respectively. As shown in the tables, the alternative would reach the breakeven year between 2027 and 2030, two years sooner than the proposed rule.

Table X-13
Breakeven Analysis for Alternative 1
(**@3 Percent** Discount, 2014 $ in Millions**)**

Year	Calendar Year	Cumulative Monetized Benefits		Total Cumulative Annual Costs		Cumulative Net Benefits		Breakeven Year	
		Low	High	Low	High	Low	High	Low	High
1	2021	$0	$0	$2,160	$2,822	-$2,822	-$2,160	*	*
2	2022	$165	$217	$5,051	$6,588	-$6,423	-$4,834	*	*
3	2023	$940	$1,240	$8,628	$11,200	-$10,260	-$7,388	*	*
4	2024	$2,776	$3,681	$12,020	$15,710	-$12,933	-$8,340	*	*
5	2025	$5,974	$7,944	$15,276	$19,930	-$13,956	-$7,332	*	*
6	2026	$10,754	$14,333	$18,392	$23,964	-$13,210	-$4,059	*	*
7	2027	$17,293	$23,089	$21,401	$27,852	-$10,559	$1,688	*	2027
8	2028	$25,720	$34,389	$24,316	$31,612	-$5,892	$10,073	*	2028
9	2029	$36,111	$48,336	$27,136	$35,247	$864	$21,200	2029	2029
10	2030	$48,501	$64,981	$29,896	$38,794	$9,707	$35,086	2030	2030
11	2031	$62,867	$84,296	$32,582	$42,242	$20,625	$51,714	2031	2031

12	2032	$79,134	$106,182	$35,192	$45,590	$33,544	$70,990	2032	2032
13	2033	$97,185	$130,482	$37,728	$48,841	$48,344	$92,754	2033	2033
14	2034	$116,874	$157,002	$40,202	$52,011	$64,863	$116,800	2034	2034
15	2035	$138,027	$185,508	$42,627	$55,112	$82,915	$142,881	2035	2035
16	2036	$160,446	$215,732	$44,978	$58,107	$102,339	$170,754	2036	2036
17	2037	$183,912	$247,380	$47,274	$61,012	$122,900	$200,106	2037	2037
18	2038	$208,194	$280,140	$49,512	$63,838	$144,356	$230,629	2038	2038
19	2039	$233,050	$313,688	$51,696	$66,652	$166,398	$261,992	2039	2039
20	2040	$258,258	$347,719	$53,851	$69,377	$188,881	$293,868	2040	2040
21	2041	$283,613	$381,959	$55,958	$72,038	$211,575	$326,001	2041	2041
22	2042	$308,929	$416,154	$57,940	$74,538	$234,391	$358,214	2042	2042
23	2043	$334,061	$450,106	$59,868	$76,967	$257,094	$390,238	2043	2043
24	2044	$358,913	$483,685	$61,744	$79,328	$279,585	$421,942	2044	2044
25	2045	$383,399	$516,774	$63,586	$81,640	$301,759	$453,188	2045	2045
26	2046	$407,468	$549,300	$65,362	$83,871	$323,597	$483,938	2046	2046
27	2047	$431,096	$581,233	$67,092	$86,041	$345,055	$514,141	2047	2047
28	2048	$454,265	$612,547	$68,774	$88,151	$366,114	$543,773	2048	2048
29	2049	$476,961	$643,222	$70,412	$90,203	$386,758	$572,810	2049	2049
30	2050	$499,166	$673,237	$72,027	$92,219	$406,947	$601,209	2050	2050
31	2051	$520,865	$702,567	$73,581	$94,154	$426,711	$628,986	2051	2051
32	2052	$542,049	$731,203	$75,085	$96,021	$446,028	$656,117	2052	2052
33	2053	$562,709	$759,131	$76,543	$97,828	$464,881	$682,588	2053	2053
34	2054	$582,848	$786,355	$77,956	$99,617	$483,231	$708,400	2054	2054
35	2055	$602,462	$812,871	$79,340	$101,338	$501,124	$733,532	2055	2055
36	2056	$621,556	$838,683	$80,666	$102,990	$518,566	$758,017	2056	2056
37	2057	$640,129	$863,794	$81,951	$104,589	$535,540	$781,842	2057	2057
38	2058	$658,179	$888,196	$83,197	$106,138	$552,041	$804,999	2058	2058
39	2059	$675,713	$911,901	$84,404	$107,639	$568,073	$827,498	2059	2059
40	2060	$692,733	$934,913	$85,589	$109,108	$583,625	$849,324	2060	2060

*not breakeven

Table X-14
Breakeven Analysis for Alternative 1
(**@7 Percent** Discount, 2014 $ in Millions)

Year	Calendar Year	Cumulative Monetized Benefits		Total Cumulative Annual Costs		Cumulative Net Benefits		Breakeven Year	
		Low	High	Low	High	Low	High	Low	High
1	2021	$0	$0	$2,119	$2,768	-$2,768	-$2,119	*	*
2	2022	$156	$205	$4,849	$6,326	-$6,170	-$4,645	*	*
3	2023	$860	$1,135	$8,102	$10,518	-$9,658	-$6,967	*	*
4	2024	$2,468	$3,271	$11,070	$14,465	-$11,998	-$7,800	*	*
5	2025	$5,161	$6,862	$13,813	$18,020	-$12,859	-$6,951	*	*
6	2026	$9,037	$12,043	$16,340	$21,291	-$12,254	-$4,297	*	*
7	2027	$14,142	$18,879	$18,689	$24,326	-$10,184	$190	*	2027
8	2028	$20,474	$27,369	$20,879	$27,152	-$6,678	$6,490	*	2028
9	2029	$27,990	$37,458	$22,919	$29,781	-$1,791	$14,538	*	2029
10	2030	$36,616	$49,047	$24,840	$32,251	$4,366	$24,206	2030	2030
11	2031	$46,245	$61,992	$26,641	$34,562	$11,683	$35,351	2031	2031

12	2032	$56,741	$76,114	$28,325	$36,722	$20,019	$47,789	2032	2032
13	2033	$67,951	$91,205	$29,900	$38,741	$29,210	$61,306	2033	2033
14	2034	$79,724	$107,062	$31,379	$40,636	$39,088	$75,683	2034	2034
15	2035	$91,898	$123,468	$32,774	$42,421	$49,477	$90,693	2035	2035
16	2036	$104,320	$140,214	$34,077	$44,081	$60,239	$106,137	2036	2036
17	2037	$116,836	$157,095	$35,302	$45,630	$71,206	$121,793	2037	2037
18	2038	$129,301	$173,912	$36,451	$47,081	$82,220	$137,462	2038	2038
19	2039	$141,583	$190,489	$37,530	$48,471	$93,112	$152,959	2039	2039
20	2040	$153,575	$206,678	$38,555	$49,768	$103,807	$168,122	2040	2040
21	2041	$165,183	$222,354	$39,520	$50,986	$114,198	$182,834	2041	2041
22	2042	$176,343	$237,428	$40,393	$52,088	$124,255	$197,034	2042	2042
23	2043	$187,008	$251,836	$41,212	$53,119	$133,889	$210,624	2043	2043
24	2044	$197,157	$265,548	$41,978	$54,083	$143,074	$223,571	2044	2044
25	2045	$206,785	$278,560	$42,702	$54,992	$151,794	$235,858	2045	2045
26	2046	$215,894	$290,869	$43,374	$55,836	$160,058	$247,495	2046	2046
27	2047	$224,505	$302,506	$44,004	$56,627	$167,878	$258,502	2047	2047
28	2048	$232,632	$313,490	$44,595	$57,367	$175,265	$268,895	2048	2048
29	2049	$240,294	$323,846	$45,148	$58,060	$182,234	$278,698	2049	2049
30	2050	$247,511	$333,602	$45,673	$58,715	$188,796	$287,929	2050	2050
31	2051	$254,301	$342,779	$46,159	$59,321	$194,980	$296,620	2051	2051
32	2052	$260,681	$351,403	$46,612	$59,883	$200,798	$304,792	2052	2052
33	2053	$266,669	$359,499	$47,034	$60,407	$206,263	$312,464	2053	2053
34	2054	$272,291	$367,098	$47,429	$60,906	$211,385	$319,669	2054	2054
35	2055	$277,560	$374,221	$47,800	$61,368	$216,192	$326,421	2055	2055
36	2056	$282,494	$380,892	$48,143	$61,795	$220,699	$332,749	2056	2056
37	2057	$287,116	$387,140	$48,463	$62,193	$224,923	$338,677	2057	2057
38	2058	$291,441	$392,987	$48,761	$62,564	$228,877	$344,226	2058	2058
39	2059	$295,484	$398,453	$49,040	$62,910	$232,574	$349,413	2059	2059
40	2060	$299,264	$403,564	$49,303	$63,237	$236,028	$354,261	2060	2060

*not breakeven

A.5 Cost-Effectiveness Analysis

Tables X-15 and X-16 show the MY year vehicles that would be cost-effective for Alternative 1. As described in the cost-effectiveness chapter, the MY net cost per fatal equivalent was used to measure the cost-effectiveness. (Note that the MY net cost is the difference between the MY costs and the MY congestion and property savings.) If the net cost per fatal equivalent for MY vehicles is less or equal to $9.7 million, these MY vehicles would be cost-effective. As shown in the tables, with this alternative, MY 2022 to MY 2024 vehicles would be cost-effective, two model years ahead of the proposed rule.

Table X-15
Cost-Effectiveness Analysis for Alternative 1
(**@3 Percent** Discount, 2014 $ in Millions)

Year	Model Year	Fatal Equivalents		MY Net Costs		Net Cost per Fatal Equivalent		Cost-Effective	
		Low	High	Low	High	Low	High	Low	High
1	2021	0.00	0.00	$2,221.39	$2,893.52	$2,221.39	$2,893.52	*	*
2	2022	45.53	590.36	$2,239.25	$3,917.09	$3.79	$86.03	2022	*
3	2023	267.37	1,346.65	$2,021.82	$4,652.41	$1.50	$17.40	2023	*
4	2024	662.64	2,008.86	$1,001.55	$4,144.52	$0.50	$6.25	2024	2024
5	2025	988.88	2,221.85	$653.52	$3,511.72	$0.29	$3.55	2025	2025
6	2026	1,286.91	2,421.53	$319.22	$3,027.37	$0.13	$2.35	2026	2026
7	2027	1,569.62	2,622.87	$14.19	$2,603.94	$0.01	$1.66	2027	2027
8	2028	1,841.89	2,819.78	-$271.71	$2,212.48	-$0.10	$1.20	2028	2028
9	2029	2,093.33	3,001.28	-$540.09	$1,845.22	-$0.18	$0.88	2029	2029
10	2030	2,340.24	3,184.43	-$771.33	$1,529.71	-$0.24	$0.65	2030	2030
11	2031	2,486.78	3,456.98	-$1,144.74	$1,333.86	-$0.33	$0.54	2031	2031
12	2032	2,597.59	3,737.93	-$1,536.86	$1,179.89	-$0.41	$0.45	2032	2032
13	2033	2,698.53	3,992.45	-$1,891.87	$1,040.43	-$0.47	$0.39	2033	2033
14	2034	2,798.02	4,233.54	-$2,214.46	$920.97	-$0.52	$0.33	2034	2034
15	2035	2,886.39	4,449.90	-$2,483.20	$836.44	-$0.56	$0.29	2035	2035
16	2036	2,965.81	4,640.93	-$2,755.92	$699.97	-$0.59	$0.24	2036	2036
17	2037	3,039.50	4,817.19	-$2,983.21	$593.09	-$0.62	$0.20	2037	2037
18	2038	3,098.80	4,963.23	-$3,173.52	$520.65	-$0.64	$0.17	2038	2038
19	2039	3,153.60	5,097.71	-$3,343.33	$565.20	-$0.66	$0.18	2039	2039
20	2040	3,208.93	5,228.81	-$3,466.53	$474.17	-$0.66	$0.15	2040	2040
21	2041	3,270.94	5,369.87	-$3,637.72	$418.30	-$0.68	$0.13	2041	2041
22	2042	3,184.64	5,256.57	-$3,602.72	$374.33	-$0.69	$0.12	2042	2042
23	2043	3,208.65	5,313.04	-$3,675.26	$344.27	-$0.69	$0.11	2043	2043
24	2044	3,231.43	5,363.55	-$3,739.14	$316.70	-$0.70	$0.10	2044	2044
25	2045	3,253.66	5,410.08	-$3,761.46	$326.77	-$0.70	$0.10	2045	2045
26	2046	3,272.33	5,451.07	-$3,845.22	$272.36	-$0.71	$0.08	2046	2046
27	2047	3,291.22	5,491.50	-$3,892.19	$254.39	-$0.71	$0.08	2047	2047
28	2048	3,307.55	5,529.12	-$3,936.80	$238.14	-$0.71	$0.07	2048	2048
29	2049	3,322.76	5,564.47	-$3,978.00	$223.86	-$0.71	$0.07	2049	2049
30	2050	3,339.62	5,603.49	-$3,972.52	$259.83	-$0.71	$0.08	2050	2050

*not cost-effective

Table X-16
Cost-Effectiveness Analysis for Alternative 1
(**@7 Percent** Discount, 2014 $ in Millions)

Year	Model Year	Fatal Equivalents		MY Net Costs		Net Cost per Fatal Equivalent		Cost-Effective	
		Low	High	Low	High	Low	High	Low	High
1	2021	0.00	0.00	$2,213.68	$2,885.80	$2,213.68	$2,885.80	*	*
2	2022	40.88	438.02	$2,440.41	$3,911.81	$5.57	$95.68	2022	*
3	2023	235.78	1,017.41	$2,466.29	$4,680.07	$2.42	$19.85	2023	*
4	2024	576.89	1,534.99	$1,648.09	$4,246.07	$1.07	$7.36	2024	2024
5	2025	856.99	1,716.26	$1,344.57	$3,676.39	$0.78	$4.29	2025	2025
6	2026	1,113.79	1,885.84	$1,051.92	$3,247.87	$0.56	$2.92	2026	2026
7	2027	1,357.83	2,057.31	$788.20	$2,876.74	$0.38	$2.12	2027	2027
8	2028	1,593.34	2,225.73	$541.65	$2,534.95	$0.24	$1.59	2028	2028
9	2029	1,769.28	2,438.49	$228.93	$2,270.15	$0.09	$1.28	2029	2029
10	2030	1,886.20	2,729.51	-$153.40	$2,131.31	-$0.06	$1.13	2030	2030
11	2031	1,993.18	2,999.97	-$524.03	$1,989.04	-$0.17	$1.00	2031	2031
12	2032	2,090.69	3,245.64	-$867.31	$1,852.81	-$0.27	$0.89	2032	2032
13	2033	2,178.14	3,469.88	-$1,180.42	$1,731.34	-$0.34	$0.79	2033	2033
14	2034	2,264.67	3,685.40	-$1,467.79	$1,629.08	-$0.40	$0.72	2034	2034
15	2035	2,343.13	3,878.07	-$1,703.91	$1,557.61	-$0.44	$0.66	2035	2035
16	2036	2,412.45	4,049.88	-$1,950.25	$1,434.48	-$0.48	$0.59	2036	2036
17	2037	2,476.63	4,205.16	-$2,148.71	$1,340.10	-$0.51	$0.54	2037	2037
18	2038	2,527.53	4,336.74	-$2,319.28	$1,278.69	-$0.53	$0.51	2038	2038
19	2039	2,575.82	4,454.99	-$2,466.91	$1,331.66	-$0.55	$0.52	2039	2039
20	2040	2,623.70	4,569.71	-$2,567.74	$1,250.27	-$0.56	$0.48	2040	2040
21	2041	2,676.12	4,692.99	-$2,714.63	$1,206.96	-$0.58	$0.45	2041	2041
22	2042	2,606.48	4,595.55	-$2,701.44	$1,140.63	-$0.59	$0.44	2042	2042
23	2043	2,627.26	4,646.68	-$2,766.86	$1,114.64	-$0.60	$0.42	2043	2043
24	2044	2,646.64	4,690.90	-$2,822.30	$1,091.37	-$0.60	$0.41	2044	2044
25	2045	2,665.16	4,731.98	-$2,837.35	$1,106.17	-$0.60	$0.42	2045	2045
26	2046	2,680.89	4,768.20	-$2,914.78	$1,055.43	-$0.61	$0.39	2046	2046
27	2047	2,696.16	4,804.78	-$2,956.71	$1,042.07	-$0.62	$0.39	2047	2047
28	2048	2,710.09	4,837.32	-$2,994.54	$1,028.76	-$0.62	$0.38	2048	2048
29	2049	2,724.68	4,866.52	-$3,027.47	$1,015.03	-$0.62	$0.37	2049	2049
30	2050	2,737.27	4,898.77	-$3,012.85	$1,056.50	-$0.62	$0.39	2050	2050

*not cost-effective

A.6 Net Benefits

Table X-17 and X-18 show the MY net benefits (i.e., net benefits over a model year vehicle's operational lifespan) at a 3 percent and 7 percent discount rate, respectively. As shown, for both discount rates, MY 2022 to MY 2024 vehicles would accrue positive net benefits. In the tables, negative net benefits indicate that the MY benefits are smaller than the MY costs.

Table X-17
MY Net Benefits of Alternative 1
(**@3 Percent** Discount, 2014 $ in **Millions**)

	Model	Monetized MY Benefits		MY Costs		MY Net Benefits	
Year	Year	Low	High	Low	High	Low	High
1	2021	$0.00	$0.00	$2,221.39	$2,893.52	-$2,893.52	-$2,221.39
2	2022	$442.16	$5,732.77	$3,064.05	$3,979.11	-$3,536.94	$2,668.72
3	2023	$2,596.37	$13,076.84	$3,903.11	$5,016.62	-$2,420.25	$9,173.73
4	2024	$6,434.69	$19,507.31	$3,807.72	$5,047.26	$1,387.43	$15,699.60
5	2025	$9,602.66	$21,575.58	$3,757.00	$4,859.00	$4,743.66	$17,818.58
6	2026	$12,496.72	$23,514.64	$3,701.42	$4,780.76	$7,715.95	$19,813.22
7	2027	$15,242.07	$25,469.83	$3,677.43	$4,742.59	$10,499.47	$21,792.40
8	2028	$17,885.92	$27,381.93	$3,666.37	$4,722.17	$13,163.75	$23,715.56
9	2029	$20,327.61	$29,144.35	$3,651.30	$4,697.58	$15,630.03	$25,493.05
10	2030	$22,725.26	$30,922.93	$3,675.70	$4,718.57	$18,006.69	$27,247.23
11	2031	$24,148.25	$33,569.51	$3,683.05	$4,722.54	$19,425.72	$29,886.46
12	2032	$25,224.34	$36,297.71	$3,683.09	$4,719.61	$20,504.73	$32,614.62
13	2033	$26,204.53	$38,769.33	$3,683.34	$4,717.73	$21,486.80	$35,085.99
14	2034	$27,170.58	$41,110.46	$3,697.24	$4,733.88	$22,436.70	$37,413.22
15	2035	$28,028.70	$43,211.48	$3,730.46	$4,769.81	$23,258.89	$39,481.02
16	2036	$28,799.95	$45,066.51	$3,724.32	$4,741.60	$24,058.35	$41,342.19
17	2037	$29,515.52	$46,778.09	$3,743.00	$4,735.17	$24,780.35	$43,035.09
18	2038	$30,091.33	$48,196.22	$3,756.46	$4,743.56	$25,347.77	$44,439.76
19	2039	$30,623.52	$49,502.09	$3,774.30	$4,862.82	$25,760.69	$45,727.80
20	2040	$31,160.81	$50,775.14	$3,834.04	$4,847.21	$26,313.60	$46,941.10
21	2041	$31,762.97	$52,145.00	$3,859.71	$4,875.87	$26,887.10	$48,285.28
22	2042	$30,924.99	$51,044.74	$3,736.44	$4,714.31	$26,210.68	$47,308.30
23	2043	$31,158.06	$51,593.06	$3,742.68	$4,716.97	$26,441.09	$47,850.38
24	2044	$31,379.29	$52,083.56	$3,749.28	$4,720.46	$26,658.83	$48,334.28
25	2045	$31,595.21	$52,535.40	$3,791.89	$4,760.83	$26,834.38	$48,743.50
26	2046	$31,776.43	$52,933.45	$3,765.32	$4,731.86	$27,044.57	$49,168.12
27	2047	$31,959.89	$53,326.02	$3,774.77	$4,739.65	$27,220.25	$49,551.25
28	2048	$32,118.44	$53,691.34	$3,782.67	$4,745.64	$27,372.79	$49,908.67
29	2049	$32,266.16	$54,034.62	$3,790.80	$4,752.11	$27,514.05	$50,243.81
30	2050	$32,429.85	$54,413.52	$3,850.74	$4,811.05	$27,618.80	$50,562.78

Table X-18

MY Net Benefits of Alternative 1
(**@7 Percent** Discount, 2014 $ in **Millions**)

Year	Model Year	Monetized MY Benefits		MY Costs		MY Net Benefits	
		Low	High	Low	High	Low	High
1	2021	$0.00	$0.00	$2,213.68	$2,885.80	-$2,885.80	-$2,213.68
2	2022	$397.01	$4,253.45	$3,052.43	$3,967.49	-$3,570.48	$1,201.01
3	2023	$2,289.57	$9,879.67	$3,887.73	$5,001.24	-$2,711.67	$5,991.94
4	2024	$5,601.98	$14,905.72	$3,792.43	$5,031.98	$570.00	$11,113.28
5	2025	$8,321.94	$16,666.00	$3,741.96	$4,843.96	$3,477.98	$12,924.04
6	2026	$10,815.63	$18,312.74	$3,686.03	$4,765.37	$6,050.26	$14,626.72
7	2027	$13,185.44	$19,977.82	$3,661.65	$4,726.81	$8,458.63	$16,316.17
8	2028	$15,472.40	$21,613.25	$3,650.18	$4,705.97	$10,766.44	$17,963.07
9	2029	$17,180.82	$23,679.34	$3,634.72	$4,681.01	$12,499.81	$20,044.61
10	2030	$18,316.26	$26,505.30	$3,658.67	$4,701.53	$13,614.73	$22,846.63
11	2031	$19,355.04	$29,131.68	$3,665.58	$4,705.07	$14,649.97	$25,466.10
12	2032	$20,301.93	$31,517.27	$3,665.22	$4,701.75	$15,600.18	$27,852.05
13	2033	$21,151.13	$33,694.76	$3,665.09	$4,699.48	$16,451.65	$30,029.67
14	2034	$21,991.46	$35,787.69	$3,678.53	$4,715.17	$17,276.29	$32,109.16
15	2035	$22,753.33	$37,658.62	$3,711.31	$4,750.65	$18,002.68	$33,947.31
16	2036	$23,426.50	$39,327.00	$3,704.74	$4,722.02	$18,704.49	$35,622.27
17	2037	$24,049.70	$40,834.83	$3,722.95	$4,715.12	$19,334.58	$37,111.87
18	2038	$24,543.94	$42,112.56	$3,735.99	$4,723.08	$19,820.85	$38,376.57
19	2039	$25,012.90	$43,260.91	$3,753.36	$4,841.89	$20,171.01	$39,507.55
20	2040	$25,477.86	$44,374.84	$3,812.60	$4,825.77	$20,652.09	$40,562.24
21	2041	$25,986.86	$45,572.02	$3,837.75	$4,853.91	$21,132.95	$41,734.27
22	2042	$25,310.61	$44,625.79	$3,714.82	$4,692.69	$20,617.92	$40,910.97
23	2043	$25,512.41	$45,122.30	$3,720.74	$4,695.02	$20,817.39	$41,401.56
24	2044	$25,700.61	$45,551.76	$3,727.00	$4,698.18	$21,002.43	$41,824.75
25	2045	$25,880.43	$45,950.65	$3,769.28	$4,738.22	$21,142.21	$42,181.37
26	2046	$26,033.22	$46,302.38	$3,742.39	$4,708.92	$21,324.29	$42,559.99
27	2047	$26,181.45	$46,657.61	$3,751.50	$4,716.38	$21,465.07	$42,906.10
28	2048	$26,316.78	$46,973.55	$3,759.08	$4,722.06	$21,594.72	$43,214.47
29	2049	$26,458.41	$47,257.12	$3,766.91	$4,728.21	$21,730.20	$43,490.22
30	2050	$26,580.64	$47,570.24	$3,826.53	$4,786.84	$21,793.80	$43,743.72

Table X-19 summarizes the MY vehicles that would be cost-effective and accrue positive net benefits for Alternative 1**.**

Table X-19
Summary of the MY that Would Be Cost-Effective and Have Positive Net Benefits
Alternative 1 – Mandate DSRC and Apps

Discount Rate	Cost-Effective	Net Benefits
At 3 Percent	2022 to 2024	2022 to 2024
At 7 Percent	2022 to 2024	2022 to 2024

B. Alternative 2 – If-Equipped

For this alternative, the agency would issue standards for V2V devices and communication protocol (e.g., DSRC units) if manufacturers choose to equip vehicles with them. The standardization would ensure the interoperability among V2V devices and consistency of safety messages. However, under this alternative, due to the lack of clarity and predictability of future implementation to ensure the consumers (especially the early adopters) that they would benefit from this feature, the consumers' willingness to purchase this feature is questionable. The per-unit cost of DSRC would also be more expensive than that under a mandate due to lower production (economies of scale).

Thus, not mandating V2V introduces two types of uncertainty: what the implementation of V2V would be and whether it would ever achieve full adoption within the fleet, which, if not successful, could cause adoption to eventually falter. The agency believes that not mandating V2V would very likely cause initial adoption to be slower than under the mandate and assumes a 5 percent adoption for MY 2021 vehicles and a 5 percent increase until it reaches 25 percent in MY 2025. This is intended to show that, in the first few years, manufacturers would attempt to increase the penetration of V2V in a select number of vehicles, most likely higher-end ones, as has been the case in other advanced safety technologies.[156] The 25 percent represents the approximate market share of all light vehicles with a base price over $30,000.[157] However, after several years, there becomes increased uncertainty because manufacturers would need to determine whether it makes sense to expand V2V implementation, continue the current level, or determine that V2V is not worth continually investing in and eliminate the technology. In this alternative analysis, the agency assumes the middle path of continuing to include V2V only on a minority of the fleet, freezing penetration at 25 percent after MY 2024. For apps, the agency also assumes the same adoption rate of V2V safety apps as in the proposal, due to their low cost once a communication system itself is installed.

[156] We note that this potential adoption rate is only an assumption; manufacturers could do anything, ranging from installing vehicles on no vehicles or more than we assume. However, we do feel confident that any schedule will be slower than the phase-in proposed today.

[157] 2016 Ward's Automotive Yearbook

We note that a 2014 study from the Highway Loss Data Institute[158] found that Government mandates could speed up the market penetration rate of partially-automatic crash avoidance technologies by up to 15 years. Based on this study and because of great uncertainties about the benefits, the agency believes that the assumed adoption rate for Alternative 2 is relatively more aggressive than the initial free-market adoption trends that were derived from the vehicle-resident crash avoidance technologies, but do not ever lead to adoption beyond 25 percent of the market. The 25 percent covers light vehicles with a base price over $30,000.[159] Thus, the benefits for Alternative 2 are considered optimistic in the first few years, before taking a path between the more optimistic scenario of increased adoption and more pessimistic scenario of decline in the later years. The agency requests comment on these assumptions.

Therefore, the main differentiating factor for calculating costs and benefits between this alternative and the proposed rule is the DSRC adoption rate. Table X-20 lists the assumed DSRC and app adoptions rates by vehicle model year for this "If-Equipped" alternative. Figure X-2 depicts the DSRC adoption for Alternative 2 and the proposed rule.

Table X-20
V2V Technology Adoption Rates in Percent
Alternative 2, If-Equipped

	Model Year							
	2021	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028+**
DSRC	5	10	15	20	25	25	25	25
Apps*	0	5	10	25	40	65	90	100

*as percent of DSRC-equipped vehicles

[158] Highway Loss Data Institute, 2014, Predicted Availability of Safety Features on Registered Vehicles Bulletin Vol. 31, No. 15, Insurance Institute for Highway Safety, Arlington, VA.

[159] Based on data from Ward's Automotive Year Book 2016

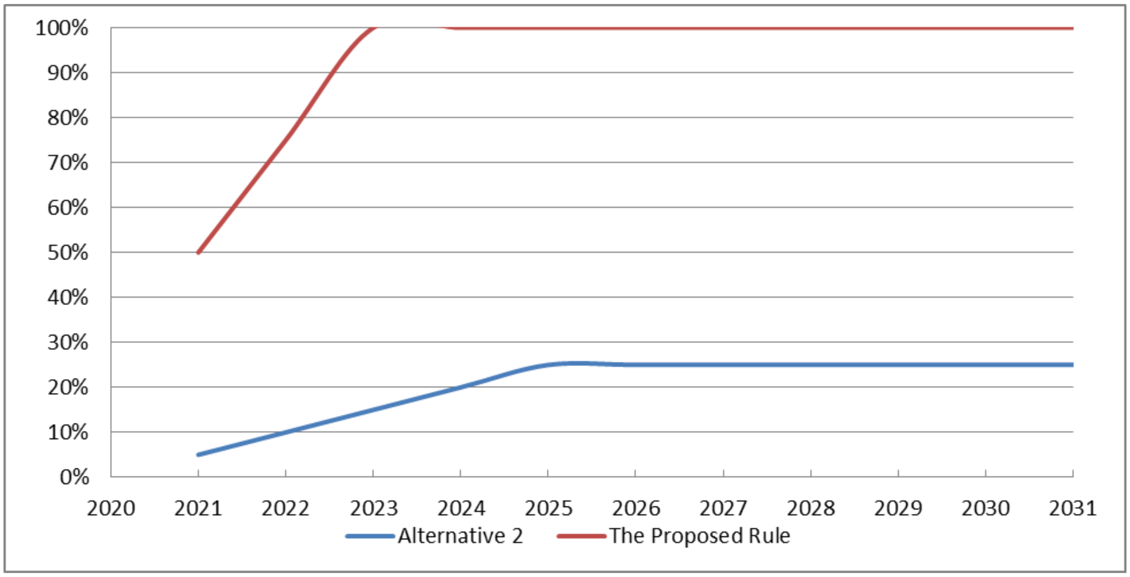


Figure X-2
DSRC Adoption Rates for Alternative 2 and the Proposed Rule

Due to a slow DSRC adoption schedule and the maximum rate of 25 percent, this alternative would accrue smaller annual benefits than would Alternative 1 and the proposed rule. In addition, Alternative 2 would have significantly less maximum annual benefits than would the other two regulatory options. Although, the cost for Alternative 2 is also less than that of Alternative 1 and the proposed rule, this alternative would breakeven and be cost-effective later than the proposed rule. Table X-21 compares the breakeven year and the MY vehicles that would be cost-effective and accrue positive net benefits of this alternative to those of the proposed rule. The range reflects the range of effectiveness rates and the two discount factors (i.e., 3 percent and 7 percent). As shown, Alternative 2 would breakeven eight or twenty-three years later than the proposed rule. Alternative 2 would be cost-effective two to five MYs later than the proposed rule and accrue positive net benefits two to seven years later than the proposed rule. These breakeven and cost-effectiveness measures were under the assumption that 25 percent of new car buyers would continue to pay the technologies for the foreseeable future.

Table X-21
Comparison of Breakeven and Cost-Effectiveness Measures
Between Alternative 2 and the Proposed Rule

	Alternative 2	**The Proposed Rule**
Breakeven Year (CY)	2037 to 2055	2029 to 2032

Cost-Effective Year (MY)	2026 to 2031	2024 to 2026
Positive Net Benefits Year (MY)	2026 to 2033	2024 to 2026

The following sections present the benefits and costs of this alternative. The organization of benefits and costs mirrors that of Alternative 1, i.e., maximum annual benefits followed by annual benefits, monetized benefits, cost, breakeven analysis, cost-effective analysis, and net benefit analysis.

B.1 Benefits

B.1.1 Maximum Annual Benefits

Alternative 2 would prevent a maximum of 27,458 to 38,460 crashes annually. Preventing these crashes, this alternative would save 62 to 85 lives, eliminate 19,071 to 26,101 MAIS 1-5 injuries, and reduce 33,554 to 46,647 PDOVs. These benefits are about 6 percent of the maximum annual benefits that could be accrued by Alternative 1 and the proposed rule. The disparity in the achievable maximum benefits demonstrates the importance of aggressively reaching full fleet penetration.

B.1.2 Annual Benefits

Because of its less aggressive DSRC adoption schedule when compared to the proposed rule, this alternative would accrue only a small portion of estimated annual benefits achieved by the proposed rule. Table X-22 shows the annual benefits of this alternative. As shown, Alternative 2 would not accrue benefits until 2024, two years later than the proposed rule. The accrued annual benefits for Alternative 2 would be less than 10 percent of that of the proposed rule (and Alternative 1).

Table X-22
Annual Benefits for Alternative 2, If-Equipped

(Undiscounted)

	Calendar	Crash Prevented		Fatalities		MAIS 1-5 Injuries		PDOVs	
Year	Year	Low	High	Low	High	Low	High	Low	High
1	2021	0	0	0	0	0	0	0	0
2	2022	0	0	0	0	0	0	0	0

3	2023	0	0	0	0	0	0	0	0
4	2024	88	123	0	0	61	84	107	149
5	2025	396	542	1	1	273	363	490	666
6	2026	913	1,250	2	3	629	837	1,129	1,536
7	2027	1,804	2,475	4	6	1,244	1,660	2,227	3,038
8	2028	2,882	3,965	7	9	1,989	2,663	3,553	4,858
9	2029	4,146	5,719	9	13	2,864	3,848	5,104	6,996
10	2030	5,531	7,639	13	17	3,823	5,143	6,805	9,339
11	2031	7,025	9,720	16	22	4,859	6,550	8,637	11,871
12	2032	8,619	11,941	20	27	5,964	8,054	10,588	14,572
13	2033	10,289	14,268	23	32	7,121	9,628	12,635	17,403
14	2034	11,970	16,613	27	37	8,287	11,216	14,693	20,254
15	2035	13,639	18,951	31	42	9,447	12,803	16,733	23,090
16	2036	15,232	21,185	34	47	10,553	14,320	18,678	25,797
17	2037	16,813	23,400	38	52	11,652	15,823	20,611	28,484
18	2038	18,295	25,486	41	57	12,683	17,242	22,418	31,007
19	2039	19,635	27,369	44	61	13,614	18,523	24,052	33,286
20	2040	20,820	29,042	47	65	14,440	19,663	25,495	35,307
21	2041	21,874	30,531	49	68	15,174	20,679	26,777	37,104
22	2042	22,752	31,774	51	71	15,786	21,527	27,844	38,602
23	2043	23,542	32,893	53	73	16,337	22,292	28,804	39,951
24	2044	24,156	33,767	54	75	16,766	22,890	29,549	41,001
25	2045	24,672	34,499	55	77	17,125	23,390	30,175	41,883
26	2046	25,067	35,064	56	78	17,402	23,779	30,651	42,560
27	2047	25,484	35,655	57	79	17,692	24,182	31,158	43,272
28	2048	25,769	36,061	58	80	17,892	24,460	31,504	43,760
29	2049	26,076	36,492	59	81	18,105	24,753	31,880	44,282
30	2050	26,318	36,836	59	82	18,274	24,989	32,172	44,696
31	2051	26,537	37,144	60	83	18,427	25,198	32,440	45,069
32	2052	26,735	37,427	60	83	18,565	25,392	32,678	45,407
33	2053	26,877	37,630	60	84	18,664	25,531	32,851	45,651
34	2054	27,042	37,857	61	84	18,778	25,684	33,054	45,930
35	2055	27,151	38,017	61	84	18,855	25,795	33,185	46,119
36	2056	27,250	38,159	61	85	18,924	25,893	33,304	46,289
37	2057	27,305	38,239	61	85	18,963	25,948	33,370	46,383
38	2058	27,393	38,362	62	85	19,024	26,032	33,477	46,533
39	2059	27,404	38,380	62	85	19,032	26,045	33,489	46,553
40	2060	27,437	38,423	62	85	19,055	26,073	33,531	46,607

B.1.3 MY Benefits

Tables X-23 and X-24 show the MY benefits (i.e., lifetime benefits for a MY vehicles) for Alternative 2, discounted at 3 percent and 7 percent, respectively. As described in the Benefits chapter, the range represents the combined benefits from the free-rider and no free rider approaches.

Table X-23
MY Benefits of Alternative 2, If-Equipped

@3 Percent Discount

Year	Model Year	Crash Prevented Low	Crash Prevented High	Fatalities Eliminated Low	Fatalities Eliminated High	MAIS 1-5 Injuries Low	MAIS 1-5 Injuries High	PDOVs Low	PDOVs High
1	2021	0	0	0	0	0	0	0	0
2	2022	1	131	0	0	0	88	1	160
3	2023	14	483	0	1	10	325	17	590
4	2024	212	1,920	0	4	146	1,294	260	2,346
5	2025	858	4,352	2	10	592	2,932	1,058	5,318
6	2026	2,158	7,714	5	17	1,490	5,199	2,661	9,421
7	2027	4,371	11,597	10	26	3,020	7,821	5,381	14,153
8	2028	6,537	13,851	15	31	4,520	9,348	8,039	16,893
9	2029	8,133	14,756	18	33	5,626	9,964	9,994	17,987
10	2030	9,599	15,678	22	35	6,643	10,592	11,789	19,102
11	2031	10,936	16,534	25	37	7,571	11,175	13,423	20,135
12	2032	12,149	17,318	27	39	8,414	11,710	14,905	21,081
13	2033	12,955	18,422	29	41	8,980	12,451	15,876	22,435
14	2034	13,459	19,866	30	44	9,331	13,433	16,489	24,182
15	2035	13,907	21,166	31	47	9,644	14,318	17,033	25,753
16	2036	14,311	22,321	32	50	9,926	15,106	17,522	27,149
17	2037	14,687	23,386	33	52	10,189	15,832	17,978	28,434
18	2038	14,999	24,272	34	54	10,407	16,438	18,356	29,500
19	2039	15,282	25,087	34	56	10,604	16,995	18,698	30,482
20	2040	15,564	25,850	35	58	10,802	17,516	19,040	31,400
21	2041	15,869	26,656	36	59	11,015	18,067	19,409	32,372
22	2042	15,462	26,163	35	58	10,733	17,737	18,908	31,766
23	2043	15,591	26,511	35	59	10,824	17,976	19,064	32,183
24	2044	15,702	26,800	35	60	10,902	18,175	19,198	32,529
25	2045	15,807	27,070	36	60	10,975	18,360	19,324	32,853
26	2046	15,902	27,306	36	61	11,042	18,522	19,440	33,135
27	2047	16,001	27,544	36	61	11,111	18,685	19,559	33,422
28	2048	16,081	27,748	36	62	11,167	18,824	19,657	33,668
29	2049	16,166	27,955	36	62	11,226	18,965	19,760	33,917
30	2050	16,254	28,167	37	63	11,288	19,110	19,867	34,173

Table X-24
MY Benefits of Alternative 2, If-Equipped

@7 Percent Discount

Year	Model Year	Crash Prevented		Fatalities Eliminated		MAIS 1-5 Injuries		PDOVs	
		Low	High	Low	High	Low	High	Low	High
1	2021	0	0	0	0	0	0	0	0
2	2022	1	95	0	0	0	64	1	116
3	2023	12	356	0	1	8	240	15	435
4	2024	195	1,456	0	3	135	980	240	1,779
5	2025	780	3,350	2	8	538	2,255	963	4,097
6	2026	1,931	5,995	4	13	1,333	4,038	2,381	7,326
7	2027	3,867	9,083	9	20	2,671	6,123	4,762	11,091
8	2028	5,737	10,906	13	24	3,966	7,357	7,057	13,308
9	2029	7,117	11,690	16	26	4,923	7,891	8,747	14,256
10	2030	8,377	12,484	19	28	5,797	8,431	10,290	15,215
11	2031	9,514	13,229	21	30	6,590	8,935	11,671	16,130
12	2032	9,995	14,713	23	33	6,925	9,938	12,255	17,930
13	2033	10,444	16,067	24	36	7,238	10,858	12,802	19,570
14	2034	10,884	17,333	25	39	7,545	11,718	13,337	21,102
15	2035	11,275	18,469	25	41	7,818	12,493	13,812	22,475
16	2036	11,629	19,491	26	43	8,065	13,189	14,241	23,709
17	2037	11,962	20,430	27	46	8,297	13,830	14,645	24,842
18	2038	12,228	21,221	28	47	8,484	14,370	14,967	25,794
19	2039	12,477	21,929	28	49	8,657	14,854	15,268	26,647
20	2040	12,719	22,605	29	50	8,827	15,317	15,561	27,460
21	2041	12,983	23,306	29	52	9,011	15,796	15,880	28,305
22	2042	12,651	22,885	28	51	8,782	15,514	15,472	27,787
23	2043	12,761	23,194	29	52	8,859	15,726	15,605	28,157
24	2044	12,856	23,445	29	52	8,926	15,899	15,719	28,458
25	2045	12,954	23,687	29	53	8,994	16,065	15,837	28,747
26	2046	13,023	23,888	29	53	9,042	16,203	15,920	28,988
27	2047	13,113	24,099	29	54	9,105	16,348	16,029	29,243
28	2048	13,177	24,280	30	54	9,150	16,471	16,107	29,460
29	2049	13,250	24,449	30	54	9,201	16,587	16,196	29,664
30	2050	13,324	24,629	30	55	9,252	16,710	16,285	29,881

B.2 Monetized Benefits

B.2.1 Monetized Maximum Annual Benefits

Undiscounted, Alternative 2 would save a maximum of 352 to 476 fatal equivalents and $3.4 to $4.6 billion annually. Of the monetized savings, $398 to $549 million are from reducing crash related congestion and property damaged vehicles, $108 to $150 million are congestion savings and $289 to $399 million are from property damaged vehicles. The remaining $3 to $4 billion results from preventing death and injury.

B.2.2 Monetized Annual Benefits

Table X-25 presents the undiscounted monetized annual benefits for Alternative 2 which allows a voluntarily adoption of DSRC and apps. Alternative 2 would not accrue benefits until year 2024. In 2024, this alternative would save 1 to 2 fatal equivalents and a total of $10.9 to $14.8 million. Of these savings, $1.5 to $2.1 million is from the reduction of property damage vehicles and crash related congestion. These benefits are approximately 1 percent of those of the proposed rule. This disparity in benefits reflects the difference in DSRC and the app adoption rates between Alternative 2 and the proposed rule. In 2060, Alternative 2 would save approximately 352 to 476 fatal equivalents annually. The associated monetized annual savings would range from $3.4 to $4.6 billion. About 15 percent of these savings ($0.5 to $0.7 billion) would be property damage and congestion savings. These benefits represent the maximum annual level expected for this alternative.

Table X-25
Annual Monetized Benefits of Alternative 2
(**Undiscounted**, 2014 $ in Millions)

	Calendar	Fatal Equivalents		Total Monetized Benefits		Property Damage and Congestion	
Year	Year	Low	High	Low	High	Low	High
1	2021	0.00	0.00	$0.00	$0.0	$0.00	$0.00
2	2022	0.00	0.00	$0.00	$0.0	$0.00	$0.00
3	2023	0.00	0.00	$0.00	$0.0	$0.00	$0.00
4	2024	1.13	1.52	$10.94	$14.8	$1.54	$2.13
5	2025	5.08	6.67	$49.31	$64.8	$6.92	$9.33
6	2026	11.71	15.39	$113.69	$149.5	$15.94	$21.53
7	2027	23.13	30.49	$224.61	$296.1	$31.50	$42.66
8	2028	36.94	48.88	$358.76	$474.6	$50.32	$68.36
9	2029	53.15	70.55	$516.14	$685.1	$72.39	$98.63
10	2030	70.91	94.26	$688.58	$915.4	$96.59	$131.78
11	2031	90.07	119.98	$874.67	$1,165.1	$122.70	$167.70
12	2032	110.50	147.45	$1,073.05	$1,431.9	$150.53	$206.07
13	2033	131.92	176.21	$1,281.01	$1,711.1	$179.71	$246.25
14	2034	153.47	205.21	$1,490.33	$1,992.7	$209.08	$286.75
15	2035	174.88	234.16	$1,698.23	$2,273.8	$238.26	$327.16
16	2036	195.31	261.81	$1,896.53	$2,542.4	$266.09	$365.77
17	2037	215.59	289.24	$2,093.49	$2,808.7	$293.73	$404.05
18	2038	234.60	315.08	$2,278.07	$3,059.7	$319.64	$440.12

19	2039	251.78	338.41	$2,444.90	$3,286.1	$343.06	$472.67
20	2040	266.98	359.16	$2,592.54	$3,487.7	$363.78	$501.62
21	2041	280.49	377.62	$2,723.77	$3,667.0	$382.21	$527.38
22	2042	291.75	393.04	$2,833.11	$3,816.7	$397.56	$548.89
23	2043	301.89	406.94	$2,931.52	$3,951.6	$411.37	$568.27
24	2044	309.77	417.79	$3,008.04	$4,057.0	$422.12	$583.39
25	2045	316.38	426.87	$3,072.26	$4,145.2	$431.14	$596.06
26	2046	321.44	433.91	$3,121.43	$4,213.6	$438.04	$605.87
27	2047	326.79	441.24	$3,173.36	$4,284.8	$445.34	$616.09
28	2048	330.45	446.29	$3,208.89	$4,333.7	$450.32	$623.12
29	2049	334.39	451.62	$3,247.18	$4,385.5	$455.70	$630.57
30	2050	337.49	455.90	$3,277.24	$4,427.1	$459.92	$636.54
31	2051	340.31	459.71	$3,304.59	$4,464.1	$463.76	$641.85
32	2052	342.84	463.23	$3,329.17	$4,498.3	$467.21	$646.75
33	2053	344.67	465.75	$3,346.94	$4,522.7	$469.71	$650.27
34	2054	346.78	468.56	$3,367.47	$4,550.0	$472.58	$654.20
35	2055	348.19	470.56	$3,381.11	$4,569.4	$474.50	$656.98
36	2056	349.45	472.32	$3,393.40	$4,586.5	$476.23	$659.43
37	2057	350.15	473.32	$3,400.22	$4,596.2	$477.19	$660.82
38	2058	351.28	474.84	$3,411.16	$4,611.0	$478.72	$662.94
39	2059	351.42	475.08	$3,412.51	$4,613.3	$478.91	$663.27
40	2060	351.84	475.60	$3,416.63	$4,618.4	$479.49	$664.01

B.2.3 Monetized MY Benefits

Tables X-26 and X-27 present the monetized MY benefits of the alternative, discounted at 3 percent and 7 percent, respectively. As shown in these two tables, the benefit disparity between the early and late MY vehicles would be difficult to convince consumers to invest in this technology. Therefore, the agency does not believe a free-market approach for DSRC would be adequate to ensure the success of V2V. On the contrary, it might jeopardize the life-saving technology and slow the agency's mission to reduce traffic related death and injuries.

Table X-26
Monetized MY Benefits of Alternative 2
(**@3 Percent** Discount, 2014 $ in Millions)

	Model	Fatal Equivalents		Total Monetized Benefits		Property Damage and Congestion	
Year	Year	Low	High	Low	High	Low	High
1	2021	0.00	0.00	$0.00	$0.00	$0.00	$0.00
2	2022	0.01	1.61	$0.08	$15.65	$0.01	$2.25
3	2023	0.18	5.96	$1.75	$57.83	$0.25	$8.32
4	2024	2.71	23.70	$26.35	$230.13	$3.70	$33.13
5	2025	10.99	53.71	$106.77	$521.58	$14.97	$75.08
6	2026	27.67	95.23	$268.69	$924.71	$37.68	$133.10
7	2027	56.03	143.19	$544.10	$1,390.49	$76.32	$200.12
8	2028	83.81	171.08	$813.82	$1,661.25	$114.16	$239.06
9	2029	104.27	182.29	$1,012.53	$1,770.14	$142.04	$254.71
10	2030	123.07	193.72	$1,195.13	$1,881.14	$167.66	$270.66
11	2031	140.21	204.33	$1,361.56	$1,984.18	$191.02	$285.46
12	2032	155.77	214.06	$1,512.65	$2,078.65	$212.22	$299.03
13	2033	166.12	227.67	$1,613.10	$2,210.78	$226.34	$318.06
14	2034	172.58	245.55	$1,675.91	$2,384.46	$235.15	$343.03
15	2035	178.33	261.67	$1,731.70	$2,540.94	$242.99	$365.51
16	2036	183.51	276.00	$1,781.97	$2,680.11	$250.05	$385.50
17	2037	188.33	289.20	$1,828.85	$2,808.34	$256.63	$403.92
18	2038	192.34	300.19	$1,867.71	$2,915.07	$262.09	$419.25
19	2039	195.96	310.31	$1,902.92	$3,013.32	$267.03	$433.36
20	2040	199.58	319.78	$1,938.10	$3,105.31	$271.97	$446.57
21	2041	203.50	329.80	$1,976.08	$3,202.54	$277.31	$460.53
22	2042	198.27	323.72	$1,925.37	$3,143.55	$270.19	$452.03
23	2043	199.93	328.05	$1,941.43	$3,185.56	$272.45	$458.06
24	2044	201.36	331.65	$1,955.35	$3,220.52	$274.40	$463.08
25	2045	202.70	335.01	$1,968.35	$3,253.13	$276.23	$467.76
26	2046	203.92	337.94	$1,980.24	$3,281.59	$277.90	$471.84
27	2047	205.19	340.90	$1,992.55	$3,310.31	$279.63	$475.97
28	2048	206.22	343.43	$2,002.56	$3,334.91	$281.04	$479.50
29	2049	207.31	345.99	$2,013.14	$3,359.77	$282.52	$483.07
30	2050	208.44	348.63	$2,024.13	$3,385.42	$284.06	$486.75

Table X-27
Monetized MY Benefits of Alternative 2
(**@7 Percent** Discount, 2014 $ in Millions)

Year	Model Year	Fatal Equivalents		Total Monetized Benefits		Property Damage and Congestion	
		Low	High	Low	High	Low	High
1	2021	0.00	0.00	$0.00	$0.00	$0.00	$0.00
2	2022	0.01	1.17	$0.07	$11.39	$0.01	$1.64
3	2023	0.16	4.39	$1.51	$42.66	$0.21	$6.14
4	2024	2.50	17.96	$24.31	$174.43	$3.41	$25.11
5	2025	10.00	41.33	$97.09	$401.38	$13.62	$57.79
6	2026	24.75	73.99	$240.36	$718.48	$33.71	$103.43
7	2027	49.57	112.13	$481.35	$1,088.88	$67.51	$156.73
8	2028	73.55	134.68	$714.24	$1,307.80	$100.19	$188.21
9	2029	91.25	144.40	$886.06	$1,402.18	$124.30	$201.78
10	2030	107.41	154.22	$1,043.02	$1,497.62	$146.32	$215.49
11	2031	121.99	163.41	$1,184.65	$1,586.80	$166.21	$228.34
12	2032	128.15	181.78	$1,244.45	$1,765.21	$174.60	$253.99
13	2033	133.91	198.55	$1,300.39	$1,928.02	$182.46	$277.39
14	2034	139.57	214.23	$1,355.27	$2,080.27	$190.16	$299.27
15	2035	144.58	228.32	$1,403.97	$2,217.10	$197.00	$318.93
16	2036	149.12	240.99	$1,448.03	$2,340.13	$203.19	$336.61
17	2037	153.39	252.63	$1,489.51	$2,453.25	$209.01	$352.86
18	2038	156.81	262.45	$1,522.70	$2,548.54	$213.67	$366.54
19	2039	160.00	271.25	$1,553.66	$2,633.97	$218.02	$378.81
20	2040	163.10	279.64	$1,583.81	$2,715.44	$222.25	$390.51
21	2041	166.48	288.34	$1,616.64	$2,799.99	$226.86	$402.65
22	2042	162.23	283.15	$1,575.37	$2,749.62	$221.08	$395.39
23	2043	163.64	286.99	$1,589.08	$2,786.90	$223.00	$400.74
24	2044	164.87	290.12	$1,600.95	$2,817.30	$224.67	$405.10
25	2045	166.12	293.13	$1,613.11	$2,846.49	$226.38	$409.29
26	2046	167.00	295.63	$1,621.71	$2,870.77	$227.59	$412.77
27	2047	168.15	298.26	$1,632.86	$2,896.30	$229.15	$416.44
28	2048	168.98	300.50	$1,640.87	$2,918.06	$230.28	$419.56
29	2049	169.92	302.60	$1,650.03	$2,938.45	$231.56	$422.49
30	2050	170.86	304.84	$1,659.16	$2,960.17	$232.84	$425.61

B.3 Costs for Alternative 2

B.3.1 Annual Costs

Table X-28 presents the annual costs for Alternative 2. Due to a slower and lower DSRC adoption, Alternative 2 has a relatively lower annul cost than the proposed rule. As shown, the undiscounted annual cost ranges from $254 to $321 million in 2021 and gradually increases to between $995 million and $1.3 billion in 2060.

Table X-28
Total Annual Costs and Cost per New Vehicle of Alternative 2
(2014 $)

Year	Calendar Year	Annual Costs (in **Millions**)		Annual Cost per New Vehicle	
		Low	High	Low	High
1	2021	$254.14	$321.36	$15.70	$19.85
2	2022	$429.72	$547.01	$26.30	$33.48
3	2023	$591.72	$752.61	$35.99	$45.78
4	2024	$747.30	$1,133.03	$45.21	$68.54
5	2025	$905.93	$1,228.62	$54.34	$73.70
6	2026	$885.55	$1,207.77	$52.87	$72.11
7	2027	$878.54	$1,203.24	$52.05	$71.28
8	2028	$874.83	$1,203.61	$51.37	$70.68
9	2029	$870.63	$1,203.78	$50.82	$70.27
10	2030	$884.83	$1,223.92	$51.15	$70.75
11	2031	$897.64	$1,242.80	$51.47	$71.26
12	2032	$897.72	$1,249.13	$51.12	$71.13
13	2033	$898.14	$1,256.06	$50.83	$71.08
14	2034	$901.92	$1,267.38	$50.56	$71.04
15	2035	$921.25	$1,294.40	$51.18	$71.91
16	2036	$909.02	$1,264.41	$50.06	$69.63
17	2037	$913.76	$1,246.91	$49.82	$67.99
18	2038	$917.31	$1,248.86	$49.61	$67.54
19	2039	$922.04	$1,357.12	$49.41	$72.73
20	2040	$954.13	$1,313.88	$50.56	$69.63
21	2041	$959.59	$1,319.61	$50.14	$68.95
22	2042	$932.51	$1,283.74	$50.24	$69.17
23	2043	$934.23	$1,284.37	$50.07	$68.83
24	2044	$935.90	$1,285.09	$49.89	$68.50
25	2045	$966.94	$1,315.39	$51.24	$69.71
26	2046	$940.09	$1,287.81	$49.56	$67.89
27	2047	$942.52	$1,289.69	$49.40	$67.59
28	2048	$944.53	$1,291.11	$49.25	$67.32
29	2049	$946.46	$1,292.53	$49.09	$67.04
30	2050	$989.91	$1,335.61	$51.05	$68.88
31	2051	$968.77	$1,298.07	$49.96	$66.95
32	2052	$966.85	$1,279.83	$49.86	$66.00
33	2053	$965.01	$1,276.71	$49.77	$65.84
34	2054	$963.29	$1,378.46	$49.68	$71.09
35	2055	$998.93	$1,338.16	$51.52	$69.01
36	2056	$959.87	$1,297.99	$49.50	$66.94
37	2057	$958.17	$1,295.23	$49.42	$66.80
38	2058	$956.52	$1,292.59	$49.33	$66.66
39	2059	$954.92	$1,290.03	$49.25	$66.53
40	2060	$994.91	$1,329.12	$51.31	$68.55

B.3.2 MY Costs

Tables X-29 and X-30 show the MY costs for Alternative 2 at a 3 percent and 7 percent discount rate, respectively.

Table X-29
Total MY Costs and Cost Per New Vehicle of Alternative 2
(@**3 Percent** Discount, 2014 $)

Year	Model Year	Total MY Costs (in Millions)		MY Cost per New Vehicle	
		Low	High	Low	High
1	2021	$257.11	$324.32	$15.88	$20.03
2	2022	$435.38	$552.67	$26.65	$33.82
3	2023	$599.66	$760.55	$36.48	$46.26
4	2024	$757.30	$1,143.03	$45.81	$69.15
5	2025	$917.44	$1,240.13	$55.04	$74.39
6	2026	$896.02	$1,218.24	$53.49	$72.73
7	2027	$888.03	$1,212.72	$52.61	$71.84
8	2028	$883.50	$1,212.28	$51.88	$71.18
9	2029	$878.29	$1,211.44	$51.27	$70.72
10	2030	$891.73	$1,230.81	$51.55	$71.15
11	2031	$903.70	$1,248.85	$51.82	$71.61
12	2032	$903.06	$1,254.47	$51.43	$71.44
13	2033	$902.65	$1,260.57	$51.08	$71.34
14	2034	$905.54	$1,271.00	$50.76	$71.24
15	2035	$924.26	$1,297.42	$51.35	$72.08
16	2036	$911.37	$1,266.76	$50.19	$69.76
17	2037	$915.57	$1,248.72	$49.92	$68.09
18	2038	$918.60	$1,250.16	$49.68	$67.61
19	2039	$922.69	$1,357.77	$49.45	$72.76
20	2040	$954.25	$1,314.00	$50.57	$69.63
21	2041	$959.80	$1,319.81	$50.15	$68.96
22	2042	$931.36	$1,282.59	$50.18	$69.10
23	2043	$932.81	$1,282.94	$49.99	$68.75
24	2044	$934.32	$1,283.50	$49.80	$68.42
25	2045	$965.12	$1,313.58	$51.15	$69.61
26	2046	$937.99	$1,285.71	$49.45	$67.78
27	2047	$940.14	$1,287.31	$49.27	$67.47
28	2048	$941.94	$1,288.52	$49.11	$67.18
29	2049	$943.80	$1,289.86	$48.95	$66.90
30	2050	$986.90	$1,332.60	$50.90	$68.73

Table X-30
Total MY Costs and Cost Per Vehicle of Alternative 2
(@**7 Percent** Discount, 2014 $)

Year	Model Year	Total MY Costs (in Million)		MY Cost per Vehicle	
		Low	High	Low	High
1	2021	$256.34	$323.55	$15.83	$19.98
2	2022	$433.83	$551.12	$26.55	$33.73
3	2023	$597.35	$758.24	$36.34	$46.12
4	2024	$754.24	$1,139.97	$45.63	$68.96
5	2025	$913.68	$1,236.37	$54.81	$74.17

6	2026	$892.17	$1,214.39	$53.26	$72.50
7	2027	$884.08	$1,208.78	$52.37	$71.61
8	2028	$879.45	$1,208.23	$51.64	$70.95
9	2029	$874.14	$1,207.29	$51.03	$70.48
10	2030	$887.47	$1,226.56	$51.30	$70.90
11	2031	$899.33	$1,244.49	$51.57	$71.36
12	2032	$898.60	$1,250.01	$51.17	$71.18
13	2033	$898.09	$1,256.01	$50.83	$71.08
14	2034	$900.86	$1,266.33	$50.50	$70.98
15	2035	$919.48	$1,292.63	$51.08	$71.81
16	2036	$906.47	$1,261.86	$49.92	$69.49
17	2037	$910.56	$1,243.71	$49.65	$67.81
18	2038	$913.49	$1,245.04	$49.40	$67.34
19	2039	$917.45	$1,352.54	$49.17	$72.48
20	2040	$948.89	$1,308.64	$50.29	$69.35
21	2041	$954.31	$1,314.33	$49.86	$68.67
22	2042	$925.96	$1,277.18	$49.89	$68.81
23	2043	$927.32	$1,277.46	$49.70	$68.46
24	2044	$928.75	$1,277.93	$49.51	$68.12
25	2045	$959.47	$1,307.92	$50.85	$69.31
26	2046	$932.26	$1,279.98	$49.14	$67.47
27	2047	$934.33	$1,281.50	$48.97	$67.16
28	2048	$936.04	$1,282.63	$48.80	$66.87
29	2049	$937.83	$1,283.89	$48.64	$66.59
30	2050	$980.85	$1,326.54	$50.59	$68.41

B.4 Breakeven Analysis

Tables X-31 and X-32 show the breakeven year for Alternative 2 at a 3 percent and 7 percent discount rate, respectively. As shown in the tables, Alternative 2 would breakeven between 2037 and 2055, eight or twenty-three years later than the proposed rule.

Table X-31
Breakeven Analysis for Alternative 2
(**@3 Percent** Discount, 2014 $ in Millions**)**

	Calendar	Cumulative Monetized Benefits		Total Cumulative Annual Costs		Cumulative Net Benefits		Breakeven Year	
Year	Year	Low	High	Low	High	Low	High	Low	High
1	2021	$0	$0	$250	$317	-$317	-$250	*	*
2	2022	$0	$0	$661	$840	-$840	-$661	*	*
3	2023	$0	$0	$1,211	$1,539	-$1,539	-$1,211	*	*
4	2024	$10	$13	$1,885	$2,561	-$2,551	-$1,872	*	*
5	2025	$53	$70	$2,678	$3,636	-$3,583	-$2,608	*	*
6	2026	$150	$197	$3,431	$4,663	-$4,513	-$3,234	*	*
7	2027	$335	$441	$4,156	$5,656	-$5,321	-$3,714	*	*
8	2028	$622	$822	$4,857	$6,620	-$5,998	-$4,035	*	*

9	2029	$1,024	$1,355	$5,534	$7,556	-$6,532	-$4,179	*	*
10	2030	$1,544	$2,046	$6,202	$8,481	-$6,937	-$4,156	*	*
11	2031	$2,185	$2,900	$6,860	$9,392	-$7,207	-$3,960	*	*
12	2032	$2,949	$3,919	$7,499	$10,281	-$7,332	-$3,580	*	*
13	2033	$3,834	$5,102	$8,120	$11,149	-$7,315	-$3,018	*	*
14	2034	$4,834	$6,439	$8,725	$12,000	-$7,165	-$2,286	*	*
15	2035	$5,941	$7,920	$9,325	$12,843	-$6,902	-$1,405	*	*
16	2036	$7,140	$9,528	$9,900	$13,642	-$6,502	-$372	*	*
17	2037	$8,425	$11,252	$10,461	$14,408	-$5,983	$791	*	2037
18	2038	$9,783	$13,076	$11,008	$15,152	-$5,369	$2,068	*	2038
19	2039	$11,198	$14,978	$11,542	$15,938	-$4,739	$3,437	*	2039
20	2040	$12,655	$16,938	$12,078	$16,676	-$4,021	$4,860	*	2040
21	2041	$14,141	$18,939	$12,601	$17,396	-$3,255	$6,337	*	2041
22	2042	$15,642	$20,960	$13,095	$18,076	-$2,434	$7,865	*	2042
23	2043	$17,149	$22,992	$13,576	$18,737	-$1,587	$9,417	*	2043
24	2044	$18,651	$25,018	$14,043	$19,378	-$727	$10,975	*	2044
25	2045	$20,140	$27,027	$14,512	$20,016	$125	$12,516	2045	2045
26	2046	$21,609	$29,010	$14,954	$20,622	$988	$14,056	2046	2046
27	2047	$23,059	$30,968	$15,385	$21,211	$1,848	$15,583	2047	2047
28	2048	$24,483	$32,890	$15,804	$21,784	$2,699	$17,087	2048	2048
29	2049	$25,881	$34,779	$16,211	$22,340	$3,541	$18,568	2049	2049
30	2050	$27,251	$36,630	$16,625	$22,899	$4,353	$20,005	2050	2050
31	2051	$28,593	$38,442	$17,018	$23,426	$5,167	$21,424	2051	2051
32	2052	$29,905	$40,215	$17,399	$23,930	$5,975	$22,815	2052	2052
33	2053	$31,185	$41,945	$17,769	$24,419	$6,767	$24,177	2053	2053
34	2054	$32,436	$43,636	$18,126	$24,931	$7,506	$25,509	2054	2054
35	2055	$33,656	$45,284	$18,487	$25,413	$8,243	$26,797	2055	2055
36	2056	$34,844	$46,890	$18,823	$25,868	$8,976	$28,067	2056	2056
37	2057	$36,000	$48,453	$19,149	$26,308	$9,692	$29,304	2057	2057
38	2058	$37,126	$49,975	$19,464	$26,735	$10,391	$30,510	2058	2058
39	2059	$38,220	$51,453	$19,771	$27,148	$11,072	$31,683	2059	2059
40	2060	$39,283	$52,890	$20,080	$27,562	$11,721	$32,810	2060	2060

*not breakeven

Table X-32
Breakeven Analysis for Alternative 2
(**@7 Percent** Discount, 2014 $ in Millions)

	Calendar	Cumulative Monetized Benefits		Total Cumulative Annual Costs		Cumulative Net Benefits		Breakeven Year	
Year	Year	Low	High	Low	High	Low	High	Low	High
1	2021	$0	$0	$246	$311	-$311	-$246	*	*
2	2022	$0	$0	$634	$805	-$805	-$634	*	*
3	2023	$0	$0	$1,134	$1,440	-$1,440	-$1,134	*	*
4	2024	$9	$12	$1,723	$2,334	-$2,326	-$1,712	*	*
5	2025	$45	$59	$2,391	$3,241	-$3,196	-$2,332	*	*
6	2026	$123	$162	$3,002	$4,073	-$3,950	-$2,839	*	*
7	2027	$268	$353	$3,568	$4,848	-$4,580	-$3,215	*	*
8	2028	$484	$639	$4,094	$5,573	-$5,089	-$3,455	*	*

9	2029	$774	$1,024	$4,584	$6,250	-$5,476	-$3,560	*	*
10	2030	$1,136	$1,506	$5,049	$6,894	-$5,757	-$3,544	*	*
11	2031	$1,566	$2,078	$5,491	$7,504	-$5,938	-$3,412	*	*
12	2032	$2,059	$2,736	$5,903	$8,078	-$6,019	-$3,167	*	*
13	2033	$2,609	$3,470	$6,288	$8,617	-$6,008	-$2,818	*	*
14	2034	$3,207	$4,270	$6,650	$9,126	-$5,919	-$2,381	*	*
15	2035	$3,844	$5,122	$6,996	$9,611	-$5,767	-$1,873	*	*
16	2036	$4,508	$6,013	$7,314	$10,054	-$5,546	-$1,301	*	*
17	2037	$5,194	$6,933	$7,613	$10,462	-$5,269	-$681	*	*
18	2038	$5,891	$7,869	$7,894	$10,844	-$4,954	-$25	*	*
19	2039	$6,590	$8,809	$8,158	$11,233	-$4,643	$651	*	2039
20	2040	$7,283	$9,741	$8,413	$11,584	-$4,301	$1,328	*	2040
21	2041	$7,963	$10,657	$8,653	$11,913	-$3,950	$2,005	*	2041
22	2042	$8,625	$11,548	$8,870	$12,213	-$3,588	$2,678	*	2042
23	2043	$9,265	$12,411	$9,074	$12,493	-$3,229	$3,337	*	2043
24	2044	$9,878	$13,238	$9,265	$12,755	-$2,877	$3,973	*	2044
25	2045	$10,464	$14,028	$9,449	$13,006	-$2,543	$4,579	*	2045
26	2046	$11,019	$14,778	$9,617	$13,235	-$2,216	$5,162	*	2046
27	2047	$11,548	$15,492	$9,774	$13,450	-$1,902	$5,718	*	2047
28	2048	$12,047	$16,166	$9,921	$13,651	-$1,604	$6,246	*	2048
29	2049	$12,519	$16,804	$10,058	$13,839	-$1,320	$6,746	*	2049
30	2050	$12,965	$17,405	$10,193	$14,021	-$1,056	$7,213	*	2050
31	2051	$13,384	$17,972	$10,316	$14,185	-$801	$7,657	*	2051
32	2052	$13,779	$18,506	$10,431	$14,337	-$558	$8,076	*	2052
33	2053	$14,151	$19,008	$10,538	$14,479	-$328	$8,470	*	2053
34	2054	$14,500	$19,480	$10,637	$14,622	-$122	$8,842	*	2054
35	2055	$14,827	$19,922	$10,734	$14,752	$76	$9,188	2055	2055
36	2056	$15,135	$20,338	$10,821	$14,869	$266	$9,516	2056	2056
37	2057	$15,422	$20,726	$10,902	$14,979	$444	$9,824	2057	2057
38	2058	$15,692	$21,091	$10,978	$15,081	$611	$10,113	2058	2058
39	2059	$15,944	$21,432	$11,048	$15,176	$768	$10,384	2059	2059
40	2060	$16,180	$21,751	$11,117	$15,268	$912	$10,634	2060	2060

*not breakeven

B.5 Cost-Effectiveness Analysis

Tables X-33 and X-34 show the MY vehicles that would be cost-effective for Alternative 2. A MY of vehicles is cost-effective when the net cost per fatal equivalent for MY vehicles is less or equal to $9.7 million. The net cost is the total cost minus the monetized savings from congestion and property damage reduction. As shown in the tables, with this alternative, MY 2026 to MY 2031 vehicles would be cost-effective, four model years behind the proposed rule.

Table X-33
Cost-Effectiveness Analysis for Alternative 2
(**@3 Percent** Discount, 2014 $ in Millions)

	Model	Fatal Equivalents		MY Net Costs		Net Cost per Fatal Equivalent		Cost-Effective	
Year	Year	Low	High	Low	High	Low	High	Low	High
1	2021	0.00	0.00	$257.11	$324.32	$257.11	$324.32	*	*
2	2022	0.01	1.61	$433.13	$552.66	$268.71	$71,187.99	*	*
3	2023	0.18	5.96	$591.33	$760.31	$99.29	$4,224.51	*	*
4	2024	2.71	23.70	$724.17	$1,139.33	$30.56	$419.94	*	*
5	2025	10.99	53.71	$842.36	$1,225.15	$15.68	$111.43	*	*
6	2026	27.67	95.23	$762.92	$1,180.56	$8.01	$42.67	2026	*
7	2027	56.03	143.19	$687.91	$1,136.41	$4.80	$20.28	2027	*
8	2028	83.81	171.08	$644.44	$1,098.12	$3.77	$13.10	2028	*
9	2029	104.27	182.29	$623.58	$1,069.40	$3.42	$10.26	2029	*
10	2030	123.07	193.72	$621.07	$1,063.15	$3.21	$8.64	2030	2030
11	2031	140.21	204.33	$618.24	$1,057.83	$3.03	$7.54	2031	2031
12	2032	155.77	214.06	$604.03	$1,042.25	$2.82	$6.69	2032	2032
13	2033	166.12	227.67	$584.59	$1,034.24	$2.57	$6.23	2033	2033
14	2034	172.58	245.55	$562.51	$1,035.85	$2.29	$6.00	2034	2034
15	2035	178.33	261.67	$558.75	$1,054.43	$2.14	$5.91	2035	2035
16	2036	183.51	276.00	$525.87	$1,016.71	$1.91	$5.54	2036	2036
17	2037	188.33	289.20	$511.64	$992.09	$1.77	$5.27	2037	2037
18	2038	192.34	300.19	$499.35	$988.07	$1.66	$5.14	2038	2038
19	2039	195.96	310.31	$489.33	$1,090.74	$1.58	$5.57	2039	2039
20	2040	199.58	319.78	$507.68	$1,042.03	$1.59	$5.22	2040	2040
21	2041	203.50	329.80	$499.26	$1,042.51	$1.51	$5.12	2041	2041
22	2042	198.27	323.72	$479.33	$1,012.39	$1.48	$5.11	2042	2042
23	2043	199.93	328.05	$474.75	$1,010.49	$1.45	$5.05	2043	2043
24	2044	201.36	331.65	$471.24	$1,009.10	$1.42	$5.01	2044	2044
25	2045	202.70	335.01	$497.37	$1,037.35	$1.48	$5.12	2045	2045
26	2046	203.92	337.94	$466.15	$1,007.81	$1.38	$4.94	2046	2046
27	2047	205.19	340.90	$464.18	$1,007.68	$1.36	$4.91	2047	2047
28	2048	206.22	343.43	$462.44	$1,007.49	$1.35	$4.89	2048	2048
29	2049	207.31	345.99	$460.73	$1,007.34	$1.33	$4.86	2049	2049
30	2050	208.44	348.63	$500.15	$1,048.53	$1.43	$5.03	2050	2050

*not cost-effective

Table X-34
Cost-Effectiveness Analysis for Alternative 2
(**@7 Percent** Discount, 2014 $ in Millions)

	Model	Fatal Equivalents		MY Net Costs		Net Cost per Fatal Equivalent		Cost-Effective	
Year	Year	Low	High	Low	High	Low	High	Low	High
1	2021	0.00	0.00	$256.34	$323.55	$256.34	$323.55	*	*
2	2022	0.01	1.17	$432.19	$551.11	$368.54	$76,845.54	*	*
3	2023	0.16	4.39	$591.21	$758.03	$134.56	$4,869.44	*	*
4	2024	2.50	17.96	$729.13	$1,136.56	$40.59	$454.20	*	*
5	2025	10.00	41.33	$855.89	$1,222.75	$20.71	$122.29	*	*
6	2026	24.75	73.99	$788.74	$1,180.69	$10.66	$47.70	*	*
7	2027	49.57	112.13	$727.36	$1,141.26	$6.49	$23.02	2027	*
8	2028	73.55	134.68	$691.23	$1,108.04	$5.13	$15.06	2028	*
9	2029	91.25	144.40	$672.37	$1,083.00	$4.66	$11.87	2029	*
10	2030	107.41	154.22	$671.98	$1,080.23	$4.36	$10.06	2030	*
11	2031	121.99	163.41	$670.99	$1,078.28	$4.11	$8.84	2031	2031
12	2032	128.15	181.78	$644.61	$1,075.40	$3.55	$8.39	2032	2032
13	2033	133.91	198.55	$620.70	$1,073.55	$3.13	$8.02	2033	2033
14	2034	139.57	214.23	$601.59	$1,076.16	$2.81	$7.71	2034	2034
15	2035	144.58	228.32	$600.54	$1,095.63	$2.63	$7.58	2035	2035
16	2036	149.12	240.99	$569.87	$1,058.68	$2.36	$7.10	2036	2036
17	2037	153.39	252.63	$557.70	$1,034.69	$2.21	$6.75	2037	2037
18	2038	156.81	262.45	$546.94	$1,031.37	$2.08	$6.58	2038	2038
19	2039	160.00	271.25	$538.64	$1,134.52	$1.99	$7.09	2039	2039
20	2040	163.10	279.64	$558.38	$1,086.39	$2.00	$6.66	2040	2040
21	2041	166.48	288.34	$551.66	$1,087.46	$1.91	$6.53	2041	2041
22	2042	162.23	283.15	$530.56	$1,056.10	$1.87	$6.51	2042	2042
23	2043	163.64	286.99	$526.58	$1,054.45	$1.83	$6.44	2043	2043
24	2044	164.87	290.12	$523.65	$1,053.26	$1.80	$6.39	2044	2044
25	2045	166.12	293.13	$550.18	$1,081.55	$1.88	$6.51	2045	2045
26	2046	167.00	295.63	$519.48	$1,052.39	$1.76	$6.30	2046	2046
27	2047	168.15	298.26	$517.89	$1,052.34	$1.74	$6.26	2047	2047
28	2048	168.98	300.50	$516.48	$1,052.35	$1.72	$6.23	2048	2048
29	2049	169.92	302.60	$515.33	$1,052.33	$1.70	$6.19	2049	2049
30	2050	170.86	304.84	$555.24	$1,093.70	$1.82	$6.40	2050	2050

*not cost-effective

B.6 Net Benefits

Table X-35 and X-36 show the MY net benefits (i.e., net benefits over a model year vehicle's operational lifespan) for Alternative 2 at a 3 percent and 7 percent discount rate, respectively. As shown, at a 3 percent discount rate, MY 2026 to MY 2031 vehicles would accrue positive net benefits. At a 7 percent discount rate, MY 2027 to MY 2033 would achieve positive net benefits. Alternative 2 would be four to six MYs behind the proposed rule to accrue positive net benefits. In these tables, negative net benefits indicate that the MY benefits are smaller than the MY costs.

Table X-35
MY Net Benefits of Alternative 2
(**@3 Percent** Discount, 2014 $ in **Millions**)

Year	Model Year	Monetized MY Benefits		MY Costs		MY Net Benefits	
		Low	High	Low	High	Low	High
1	2021	$0.00	$0.00	$257.11	$324.32	-$324.32	-$257.11
2	2022	$0.08	$15.65	$435.38	$552.67	-$552.60	-$419.73
3	2023	$1.75	$57.83	$599.66	$760.55	-$758.80	-$541.83
4	2024	$26.35	$230.13	$757.30	$1,143.03	-$1,116.67	-$527.17
5	2025	$106.77	$521.58	$917.44	$1,240.13	-$1,133.36	-$395.86
6	2026	$268.69	$924.71	$896.02	$1,218.24	-$949.55	**$28.69**
7	2027	$544.10	$1,390.49	$888.03	$1,212.72	-$668.62	$502.46
8	2028	$813.82	$1,661.25	$883.50	$1,212.28	-$398.46	$777.75
9	2029	$1,012.53	$1,770.14	$878.29	$1,211.44	-$198.91	$891.86
10	2030	$1,195.13	$1,881.14	$891.73	$1,230.81	-$35.68	$989.41
11	2031	$1,361.56	$1,984.18	$903.70	$1,248.85	**$112.71**	$1,080.48
12	2032	$1,512.65	$2,078.65	$903.06	$1,254.47	$258.18	$1,175.58
13	2033	$1,613.10	$2,210.78	$902.65	$1,260.57	$352.53	$1,308.13
14	2034	$1,675.91	$2,384.46	$905.54	$1,271.00	$404.90	$1,478.92
15	2035	$1,731.70	$2,540.94	$924.26	$1,297.42	$434.28	$1,616.67
16	2036	$1,781.97	$2,680.11	$911.37	$1,266.76	$515.21	$1,768.74
17	2037	$1,828.85	$2,808.34	$915.57	$1,248.72	$580.13	$1,892.77
18	2038	$1,867.71	$2,915.07	$918.60	$1,250.16	$617.55	$1,996.47
19	2039	$1,902.92	$3,013.32	$922.69	$1,357.77	$545.15	$2,090.63
20	2040	$1,938.10	$3,105.31	$954.25	$1,314.00	$624.09	$2,151.06
21	2041	$1,976.08	$3,202.54	$959.80	$1,319.81	$656.26	$2,242.74
22	2042	$1,925.37	$3,143.55	$931.36	$1,282.59	$642.79	$2,212.19
23	2043	$1,941.43	$3,185.56	$932.81	$1,282.94	$658.49	$2,252.75
24	2044	$1,955.35	$3,220.52	$934.32	$1,283.50	$671.85	$2,286.20
25	2045	$1,968.35	$3,253.13	$965.12	$1,313.58	$654.77	$2,288.01
26	2046	$1,980.24	$3,281.59	$937.99	$1,285.71	$694.53	$2,343.59
27	2047	$1,992.55	$3,310.31	$940.14	$1,287.31	$705.24	$2,370.17
28	2048	$2,002.56	$3,334.91	$941.94	$1,288.52	$714.03	$2,392.97
29	2049	$2,013.14	$3,359.77	$943.80	$1,289.86	$723.28	$2,415.97
30	2050	$2,024.13	$3,385.42	$986.90	$1,332.60	$691.53	$2,398.52

Table X-36
MY Net Benefits of Alternative 2
(**@7 Percent** Discount, 2014 $ in **Millions**)

Year	Model Year	Monetized MY Benefits		MY Costs		MY Net Benefits	
		Low	High	Low	High	Low	High
1	2021	$0.00	$0.00	$256.34	$323.55	-$323.55	-$256.34
2	2022	$0.07	$11.39	$433.83	$551.12	-$551.05	-$422.45
3	2023	$1.51	$42.66	$597.35	$758.24	-$756.73	-$554.69
4	2024	$24.31	$174.43	$754.24	$1,139.97	-$1,115.66	-$579.81
5	2025	$97.09	$401.38	$913.68	$1,236.37	-$1,139.27	-$512.30
6	2026	$240.36	$718.48	$892.17	$1,214.39	-$974.04	-$173.69
7	2027	$481.35	$1,088.88	$884.08	$1,208.78	-$727.43	**$204.79**
8	2028	$714.24	$1,307.80	$879.45	$1,208.23	-$493.99	$428.35
9	2029	$886.06	$1,402.18	$874.14	$1,207.29	-$321.24	$528.04
10	2030	$1,043.02	$1,497.62	$887.47	$1,226.56	-$183.54	$610.15
11	2031	$1,184.65	$1,586.80	$899.33	$1,244.49	-$59.84	$687.47
12	2032	$1,244.45	$1,765.21	$898.60	$1,250.01	-$5.55	$866.61
13	2033	$1,300.39	$1,928.02	$898.09	$1,256.01	**$44.38**	$1,029.93
14	2034	$1,355.27	$2,080.27	$900.86	$1,266.33	$88.95	$1,179.41
15	2035	$1,403.97	$2,217.10	$919.48	$1,292.63	$111.34	$1,297.63
16	2036	$1,448.03	$2,340.13	$906.47	$1,261.86	$186.17	$1,433.66
17	2037	$1,489.51	$2,453.25	$910.56	$1,243.71	$245.81	$1,542.69
18	2038	$1,522.70	$2,548.54	$913.49	$1,245.04	$277.66	$1,635.06
19	2039	$1,553.66	$2,633.97	$917.45	$1,352.54	$201.12	$1,716.51
20	2040	$1,583.81	$2,715.44	$948.89	$1,308.64	$275.17	$1,766.55
21	2041	$1,616.64	$2,799.99	$954.31	$1,314.33	$302.32	$1,845.68
22	2042	$1,575.37	$2,749.62	$925.96	$1,277.18	$298.19	$1,823.66
23	2043	$1,589.08	$2,786.90	$927.32	$1,277.46	$311.62	$1,859.58
24	2044	$1,600.95	$2,817.30	$928.75	$1,277.93	$323.02	$1,888.55
25	2045	$1,613.11	$2,846.49	$959.47	$1,307.92	$305.19	$1,887.02
26	2046	$1,621.71	$2,870.77	$932.26	$1,279.98	$341.74	$1,938.51
27	2047	$1,632.86	$2,896.30	$934.33	$1,281.50	$351.37	$1,961.97
28	2048	$1,640.87	$2,918.06	$936.04	$1,282.63	$358.24	$1,982.02
29	2049	$1,650.03	$2,938.45	$937.83	$1,283.89	$366.14	$2,000.62
30	2050	$1,659.16	$2,960.17	$980.85	$1,326.54	$332.61	$1,979.32

Table X-37 summarizes the MY vehicles that would be cost-effective and accrue positive net benefits for Alternative 2**.**

Table X-37
Summary of the MY that Would Be Cost-Effective and Have Positive Net Benefits
Alternative 2 – If-Equipped with DSRC and Apps

Discount Rate	Cost-Effective	Net Benefits
At 3 Percent	2026 to 2030	2026 to 2031
At 7 Percent	2027 to 2031	2027 to 2033

C. Summary

The agency examined two regulatory alternatives. Alternative 1 would mandate the installation of DSRC and the IMA and LTA apps. Alternative 2 (If-Equipped) allows manufacturers to voluntarily install DSRC and apps and the install DSRC would be required to comply with the proposed criteria. Alternative 1 is a relatively more stringent approach than the proposed rule since Alternative 1 would mandate app adoption with a phase-in schedule more stringent than the free-market app adoption trend specified in the proposed rule. For Alternative 2, due to the uncertainty as to when and whether the manufactures would be able to persuade the consumers to invest in the communication technologies that they might not be able to benefit from, the DSRC adoption rates for this alternative is slower than that of the proposed rule. Table X-38 summaries the technology adoption rates for the two alternatives we examined and the proposed rule.

Table X-38
V2V Technology Adoption Rates in Percent

DSRC Adoption Rates

Regulation Alternatives	Model Year							
	2021	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028+**
The Proposed Rule Mandating DSRC	50	75	100	100	100	100	100	100
Alternative 1 Mandating DSRC and Apps	50	75	100	100	100	100	100	100
Alternative 2 If-Equipped	5	10	15	20	25	25	25	25

App Adoption Rates*

Regulation Alternatives	Model Year							
	2021	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028+**
The Proposed Rule Mandating DSRC	0	5	10	25	40	65	90	100
Alternative 1 Mandating DSRC and Apps	50	75	100	100	100	100	100	100
Alternative 2 If-Equipped	0	5	10	15	20	25	25	25

*as percent of DSRC-equipped vehicles

The cost and benefit analyses for the proposed rule and the two alternatives were based on the technology adoption rates specified in Table X-38. Table X-39 shows the cost-benefit measures for the proposed rule and the two alternatives, i.e., the breakeven year and the MY vehicles that the proposed rule and each regulatory alternative would be cost-effective and have positive net benefits. These measures are presented at a 3 percent and a 7 percent discount rate. As shown, Alternative 1 would breakeven between 2027 and 2029 when taking into account both discount rates, two to three years earlier than the proposed rule. Alternative 1 would become cost-effective and accrue positive benefits between MY 2022 and MY 2024 vehicles, two MYs earlier than the proposed rule.

In comparison, Alternative 2 would breakeven between 2037 and 2055, eight to twenty-three years behind the proposed rule. Alternative 2 would be cost-effective between 2026 MY and 2031 MY vehicles, about two to five MYs behind the proposed rule. Alternative 2 would accrue positive benefits between MY 2026 and MY 2033 vehicles, about two to seven years later than the proposed rule.

Table X-39
Summary of Cost-Benefit Measures Among the Regulatory Options

At 3 Percent Discount

Cost-Benefit Measures	**Alternative 1** Mandating DSRC Radios and Apps	**The Proposed Rule** Mandating DSRC Only	**Alternative 2** If-Equipped
Breakeven (CY)	2027 to 2029	2029 to 2031	2037 to 2045
Cost-Effectiveness (MY)	2022 to 2024	2024 to 2026	2026 to 2030
Positive Net Benefits (MY)	2022 to 2024	2024 to 2026	2026 to 2031

At 7 Percent Discount

Cost-Benefit Measures	**Alternative 1** Mandating DSRC Radios and Apps	**The Proposed Rule** Mandating DSRC Only	**Alternative 2** If-Equipped
Breakeven (CY)	2027 to 2030	2030 to 2032	2039 to 2055
Cost-Effectiveness (MY)	2022 to 2024	2024 to 2026	2027 to 2031
Positive Net Benefits (MY)	2022 to 2024	2024 to 2026	2027 to 2033

CY: calendar year, MY: model year of vehicles

Although, Alternative 1 would guarantee the safety benefits from V2V, the agency decided not to select Alternative 1 for two major reasons. First, due to the mandate of DSRC, manufacturers would have already incurred the costs to enable these life-saving applications. As a result, the residual incremental cost for apps is very small and we believe that manufacturers will most likely make the investment in apps to fully utilize the already installed V2V technology and to ensure their competiveness in the market. Second, in contrast to the vehicle-resident safety systems that rely exclusively on the data from its own sensors and vehicle performance, the V2V-based apps require inputs from nearby vehicles or roadway equipment. These apps thus need to be designed to consider the variability of the incoming messages that would be sent from diverse vehicle models and production lines. This creates unique challenges for testing and deployment. Therefore, the agency believes that allowing a free-market approach for apps development is the preferred approach for considering these challenges.

The agency also decided not to select Alternative 2 because of comments on the ANPRM from the industry, the cooperative nature of the V2V communication technology, the associated costs, and the needed supporting infrastructure (i.e., SCMS). The majority of commenters from the automobile manufacturers and suppliers commented that they would mostly wait or halt the investment in V2V if NHTSA does not mandate DSRC. Furthermore, the benefit of V2V to a consumer depends on when the consumer would make the investment. Early adopters might not benefit from V2V technology or they would benefit less than the late adopters. The benefit disparity among early and late adopters increases when the technology adoption is slower and prolonged longer. Absent a mandate a prolonged period of low adoption (or eventually faltered adoption) is highly likely. Specifically, consumers would be less likely to pay for a technology when there is no predicable or foreseeable benefit to them. Given the uncertainty and variability of the safety benefits under Alternative 2, this alternative is not selected.

CHAPTER XI. SENSITIVITY ANALYSIS

The sensitivity analysis examines the impact of various VSLs on the monetized benefits and the subsequent cost-benefit measures (i.e., breakeven year and MY vehicles that would be cost-effective and have positive net benefits). The DOT 2015 guidance on treatment of VSL[160] specifies that the economic analyses should calculate high and low alternative estimates of the economic values of fatalities and injuries by using alternative VSLs of $5.2 million and $13.0 million in 2013 dollars. The corresponding VSLs in 2014 dollars are $5.3 million and $13.2 million, respectively. The upper and lower benefit and cost estimates of the proposed rule vary from year to year and also MY vehicles to MY vehicles. If other factors that would influence the estimated costs and benefits remain the same in this analysis, the monetized benefits for an alternative VSL can be adjusted from the primary estimated figures by a factor which is expected to be proportional to this VSL to the $9.4 million used in the main analysis. The primary estimates are referring to those estimated in the main analysis using $9.4 million VSL. Ultimately, the cost-benefit measures are used to determine the normalized bases for assessing the impacts of these two upper and lower VSL values.

As discussed in the Monetized Benefits chapter, VSL is part of comprehensive costs[161] and affects Quality-Adjusted Life Years (i.e., QALYs). QALYs comprise a relatively larger portion of comprehensive costs for more severity injuries when compared to the lower severity injuries. As a result, the VSL impacts (i.e., change in VSL values) on the comprehensive costs are disproportionally higher on severe injuries (MAIS 3+) than PDOVs and minor injuries (MAIS 0 & 1). Lower VSL reduces the comprehensive costs of severe injuries relatively more than that of minor injuries. Thus, the low VSL induces relatively higher fatality ratios for PDOVs and MAIS 0-1 injuries than does the high VSL. Consequently, the fatal equivalents are different for different VSLs even with the same injury benefits (i.e., number of injuries prevented). Table XI-1 lists the unit comprehensive costs and relative fatality ratios for $5.3 million and $13.2 million

[160] Issued on June 17, 2015

[161] Included lost productivity, medical costs, legal and court costs, emergency service costs (EMS), insurance administration costs, congestion costs, property damage, workplace losses, and values for more intangible consequences such as physical pain or lost quality-of-life.

VSLs. As shown, when the VSL is $5.3 million, the comprehensive cost of a fatality is $5.6 million and it is $13.5 million when the VSL is $13.2 million. A single PDOV, for example, equates to 0.0012 fatal equivalents with the $5.3 million VSL. It becomes 0.0005 fatal equivalents when the VSL increases to $13.2 million. As illustrated, the proposed rule would save more fatal equivalents with the $5.3 million VSL than the $13.2 million VSL although the estimated safety benefits (i.e., number of lives saved and injuries prevented) are identical for both alternative VSLs.

Table XI-1
Unit Comprehensive Costs and Relative Fatal Ratios for Two Alternative VSLs
(2014 $)

Injury Category	**$5.3 Million VSL**		**$13.2 Million VSL**	
	Comprehensive Cost	Relative Fatality Ratio	Comprehensive Cost	Relative Fatality Ratio
PDOVs	$6,591	0.0012	$6,591	0.0005
MAIS 0	$4,753	0.0009	$4,753	0.0004
MAIS 1	$34,778	0.0062	$58,529	0.0043
MAIS 2	$255,505	0.0457	$627,604	0.0465
MAIS 3	$632,222	0.1131	$1,463,507	0.1084
MAIS 4	$1,515,930	0.2713	$3,621,852	0.2682
MAIS 5	$3,514,029	0.6288	$8,208,810	0.6078
Fatality	$5,588,659	1.0000	$13,505,659	1.0000

Note that since VSLs do not influence injury benefits (i.e., crashes, fatalities, MAIS 1-5, PDOVs would be reduced) and costs. Therefore, these estimates are not repeated here. Please see the corresponding chapters in the main body of the analysis for these estimates, i.e., for $9.4 million VSL.

A. Impacts of $5.3 Million VSL

<u>Monetized Annual Benefits</u>

Table XI-2 shows the fatal equivalents and monetized annual benefits of the proposed rule with $5.3 million VSL. With the $5.3 million VSL, the proposed rule would save $12.5 to $16.3 million in 2022, the first year for app adoption. In 2060, when the adoption rate almost reaches the full app adoption, the proposed rule would save $35.7 to $48.3 billion. When compared to the primary estimates, these savings are 65.4 percent of the primary estimates.

Table XI-2
Annual Monetized Benefits of the Proposed Rule for **$5.3 Million VSLs**
(Undiscounted, 2014 $ in Millions)

Year	Calendar Year	Fatal Equivalents		Total Monetized Benefits	
		Low	High	Low	High
1	2021	0.00	0.00	$0.0	$0.0
2	2022	2.24	2.92	$12.5	$16.3
3	2023	14.70	19.28	$82.2	$107.7
4	2024	57.70	75.65	$322.4	$422.8
5	2025	146.55	192.38	$819.0	$1,075.2
6	2026	309.68	407.47	$1,730.7	$2,277.2
7	2027	558.09	736.53	$3,119.0	$4,116.2
8	2028	861.07	1,139.68	$4,812.2	$6,369.3
9	2029	1,195.14	1,585.81	$6,679.2	$8,862.5
10	2030	1,555.69	2,068.37	$8,694.2	$11,559.4
11	2031	1,935.98	2,578.81	$10,819.5	$14,412.1
12	2032	2,328.54	3,106.80	$13,013.4	$17,362.8
13	2033	2,726.32	3,643.02	$15,236.5	$20,359.6
14	2034	3,123.11	4,179.10	$17,454.0	$23,355.5
15	2035	3,511.40	4,704.91	$19,624.0	$26,294.1
16	2036	3,882.57	5,208.67	$21,698.4	$29,109.5
17	2037	4,230.73	5,682.32	$23,644.1	$31,756.5
18	2038	4,550.29	6,118.14	$25,430.0	$34,192.2
19	2039	4,834.55	6,507.13	$27,018.7	$36,366.1
20	2040	5,083.36	6,848.82	$28,409.2	$38,275.7
21	2041	5,295.93	7,141.88	$29,597.1	$39,913.5
22	2042	5,471.78	7,385.27	$30,579.9	$41,273.7
23	2043	5,618.12	7,588.59	$31,397.7	$42,410.0
24	2044	5,739.42	7,757.47	$32,075.6	$43,353.8
25	2045	5,839.04	7,896.30	$32,632.4	$44,129.7
26	2046	5,923.35	8,013.73	$33,103.6	$44,786.0
27	2047	5,997.48	8,116.69	$33,517.8	$45,361.4
28	2048	6,062.85	8,207.17	$33,883.2	$45,867.1
29	2049	6,121.52	8,288.26	$34,211.1	$46,320.2
30	2050	6,173.51	8,359.94	$34,501.6	$46,720.8
31	2051	6,216.40	8,419.23	$34,741.3	$47,052.2
32	2052	6,254.18	8,471.61	$34,952.5	$47,344.9
33	2053	6,285.27	8,514.79	$35,126.2	$47,586.2
34	2054	6,311.73	8,551.65	$35,274.1	$47,792.2
35	2055	6,333.88	8,582.50	$35,397.9	$47,964.7
36	2056	6,352.53	8,608.50	$35,502.1	$48,109.9
37	2057	6,366.07	8,627.57	$35,577.8	$48,216.5
38	2058	6,373.39	8,638.25	$35,618.7	$48,276.2
39	2059	6,378.15	8,645.47	$35,645.3	$48,316.6
40	2060	6,380.52	8,649.29	$35,658.5	$48,337.9

Monetized MY Benefits

Tables XI-3 and XI-4 present monetized MY benefits at a 3 percent and 7 percent discount rate, respectively. The monetized benefits per MY vehicles would range from $22.0 to $430.9 million for MY 2022 vehicles and $21.2 to $35.6 billion for MY 2050 vehicles at a 3 percent discount rate. At a 7 percent discount rate, the savings would be $20.7 to $325.0 million for MY 2022 vehicles and $17.4 to $31.1 billion for MY 2050 vehicles. These savings are about 65.4 percent of the primary estimates.

Table XI-3
Monetized MY Benefits for **$5.3 Million VSLs**
(**@3 Percent** Discount, 2014 $ in Millions)

Year	Model Year	Fatal Equivalents		Total Monetized Benefits	
		Low	High	Low	High
1	2021	0.00	0.00	$0.0	$0.0
2	2022	3.94	77.10	$22.0	$430.9
3	2023	26.45	236.95	$147.8	$1,324.2
4	2024	118.15	659.03	$660.3	$3,683.1
5	2025	291.76	1,155.55	$1,630.6	$6,458.0
6	2026	664.58	2,016.59	$3,714.1	$11,270.0
7	2027	1,260.15	2,978.41	$7,042.5	$16,645.3
8	2028	1,819.51	3,511.64	$10,168.6	$19,625.4
9	2029	2,204.73	3,693.58	$12,321.5	$20,642.2
10	2030	2,551.73	3,880.28	$14,260.7	$21,685.6
11	2031	2,858.85	4,048.85	$15,977.1	$22,627.6
12	2032	3,128.83	4,201.15	$17,485.9	$23,478.8
13	2033	3,226.33	4,517.01	$18,030.8	$25,244.0
14	2034	3,324.51	4,819.15	$18,579.5	$26,932.6
15	2035	3,409.73	5,084.38	$19,055.8	$28,414.8
16	2036	3,483.65	5,315.58	$19,468.9	$29,707.0
17	2037	3,551.23	5,520.38	$19,846.6	$30,851.5
18	2038	3,605.14	5,688.76	$20,147.9	$31,792.5
19	2039	3,653.77	5,839.42	$20,419.7	$32,634.5
20	2040	3,704.16	5,984.75	$20,701.3	$33,446.7
21	2041	3,762.54	6,140.22	$21,027.6	$34,315.6
22	2042	3,653.63	6,002.35	$20,418.9	$33,545.1
23	2043	3,672.90	6,060.75	$20,526.6	$33,871.4
24	2044	3,692.40	6,112.78	$20,635.6	$34,162.2
25	2045	3,710.90	6,161.47	$20,738.9	$34,434.3
26	2046	3,728.30	6,204.73	$20,836.2	$34,676.1
27	2047	3,746.31	6,248.67	$20,936.8	$34,921.7
28	2048	3,761.31	6,290.15	$21,020.7	$35,153.5
29	2049	3,776.63	6,329.47	$21,106.3	$35,373.2
30	2050	3,795.70	6,371.80	$21,212.9	$35,609.8

Table XI-4
Monetized MY Benefits for **$5.3 Million VSLs**
(**@7 Percent** Discount, 2014 $ in Millions)

Year	Model Year	Fatal Equivalents		Total Monetized Benefits	
		Low	High	Low	High
1	2021	0.00	0.00	$0.0	$0.0
2	2022	3.71	58.15	$20.7	$325.0
3	2023	24.73	181.27	$138.2	$1,013.1
4	2024	109.14	511.48	$609.9	$2,858.5
5	2025	266.02	903.85	$1,486.7	$5,051.3
6	2026	597.64	1,586.81	$3,340.0	$8,868.1
7	2027	1,120.37	2,360.44	$6,261.3	$13,191.7
8	2028	1,605.14	2,794.00	$8,970.6	$15,614.7
9	2029	1,937.44	2,952.77	$10,827.7	$16,502.0
10	2030	2,237.25	3,114.73	$12,503.2	$17,407.1
11	2031	2,434.80	3,348.54	$13,607.3	$18,713.9
12	2032	2,530.21	3,667.39	$14,140.5	$20,495.8
13	2033	2,616.61	3,952.21	$14,623.3	$22,087.5
14	2034	2,702.68	4,217.09	$15,104.4	$23,567.9
15	2035	2,777.85	4,449.39	$15,524.5	$24,866.1
16	2036	2,842.71	4,652.61	$15,886.9	$26,001.8
17	2037	2,902.73	4,834.31	$16,222.4	$27,017.3
18	2038	2,948.81	4,981.77	$16,479.9	$27,841.4
19	2039	2,991.19	5,114.05	$16,716.7	$28,580.7
20	2040	3,034.19	5,241.45	$16,957.1	$29,292.6
21	2041	3,082.80	5,374.55	$17,228.7	$30,036.5
22	2042	2,992.91	5,254.29	$16,726.4	$29,364.4
23	2043	3,010.03	5,306.13	$16,822.0	$29,654.1
24	2044	3,025.69	5,350.12	$16,909.5	$29,900.0
25	2045	3,042.72	5,393.44	$17,004.7	$30,142.1
26	2046	3,055.21	5,430.11	$17,074.5	$30,347.0
27	2047	3,071.91	5,470.54	$17,167.9	$30,572.9
28	2048	3,083.97	5,504.91	$17,235.3	$30,765.0
29	2049	3,098.02	5,537.38	$17,313.8	$30,946.5
30	2050	3,112.44	5,573.77	$17,394.4	$31,149.9

Breakeven Analysis

For the $5.3 million lower range VSL, the proposed rule would reach the breakeven year between 2031 and 2034 at a 3 percent discount rate and 2031 to 2035 at a 7 percent discount rate, as shown in Table XI-5. The proposed rule would reach the breakeven year three years later than the breakeven year that was estimated in the main analysis using $9.4 million VSL.

Table XI-5
Breakeven Analysis for **$5.3 Million VSLs**
(@3 Percent Discount**,** 2014 $ in Millions**)**

		Cumulative Monetized Benefits		Total Cumulative Annual Costs		Cumulative Net Benefits		Breakeven Year	
Year	Calendar Year	Low	High	Low	High	Low	High	Low	High
1	2021	$0	$0	$2,160	$2,822	-$2,822	-$2,160	*	*
2	2022	$12	$16	$5,040	$6,578	-$6,566	-$5,025	*	*
3	2023	$88	$116	$8,600	$11,172	-$11,083	-$8,484	*	*
4	2024	$379	$497	$11,973	$15,663	-$15,284	-$11,476	*	*
5	2025	$1,096	$1,438	$15,213	$19,868	-$18,772	-$13,775	*	*
6	2026	$2,567	$3,374	$18,320	$23,892	-$21,325	-$14,946	*	*
7	2027	$5,141	$6,771	$21,324	$27,775	-$22,634	-$14,554	*	*
8	2028	$8,996	$11,874	$24,236	$31,533	-$22,536	-$12,362	*	*
9	2029	$14,192	$18,767	$27,053	$35,164	-$20,972	-$8,286	*	*
10	2030	$20,757	$27,497	$29,809	$38,707	-$17,950	-$2,312	*	*
11	2031	$28,690	$38,064	$32,492	$42,152	-$13,462	$5,572	*	2031
12	2032	$37,953	$50,422	$35,099	$45,497	-$7,543	$15,324	*	2032
13	2033	$48,483	$64,493	$37,632	$48,744	-$261	$26,861	*	2033
14	2034	$60,195	$80,164	$40,102	$51,911	$8,284	$40,062	2034	2034
15	2035	$72,978	$97,292	$42,524	$55,009	$17,969	$54,769	2035	2035
16	2036	$86,700	$115,701	$44,872	$58,001	$28,699	$70,829	2036	2036
17	2037	$101,217	$135,200	$47,165	$60,903	$40,315	$88,035	2037	2037
18	2038	$116,376	$155,582	$49,400	$63,726	$52,650	$106,182	2038	2038
19	2039	$132,015	$176,630	$51,581	$66,537	$65,477	$125,049	2039	2039
20	2040	$147,978	$198,138	$53,734	$69,259	$78,718	$144,404	2040	2040
21	2041	$164,126	$219,914	$55,837	$71,918	$92,208	$164,077	2041	2041
22	2042	$180,324	$241,777	$57,817	$74,415	$105,909	$183,960	2042	2042
23	2043	$196,469	$263,584	$59,742	$76,841	$119,627	$203,842	2043	2043
24	2044	$212,484	$285,231	$61,616	$79,200	$133,284	$223,615	2044	2044
25	2045	$228,301	$306,621	$63,455	$81,509	$146,792	$243,165	2045	2045
26	2046	$243,880	$327,697	$65,229	$83,738	$160,142	$262,467	2046	2046
27	2047	$259,194	$348,422	$66,956	$85,906	$173,288	$281,466	2047	2047
28	2048	$274,224	$368,769	$68,637	$88,014	$186,211	$300,132	2048	2048
29	2049	$288,959	$388,719	$70,273	$90,063	$198,896	$318,447	2049	2049
30	2050	$303,384	$408,253	$71,886	$92,078	$211,307	$336,367	2050	2050
31	2051	$317,486	$427,352	$73,437	$94,010	$223,475	$353,915	2051	2051
32	2052	$331,261	$446,010	$74,940	$95,875	$235,385	$371,071	2052	2052
33	2053	$344,700	$464,217	$76,396	$97,681	$247,019	$387,821	2053	2053
34	2054	$357,804	$481,972	$77,806	$99,468	$258,336	$404,165	2054	2054
35	2055	$370,572	$499,272	$79,189	$101,187	$269,385	$420,084	2055	2055
36	2056	$383,005	$516,121	$80,513	$102,837	$280,168	$435,607	2056	2056
37	2057	$395,101	$532,514	$81,797	$104,435	$290,667	$450,718	2057	2057
38	2058	$406,859	$548,450	$83,040	$105,982	$300,877	$465,410	2058	2058
39	2059	$418,283	$563,936	$84,246	$107,481	$310,802	$479,690	2059	2059
40	2060	$429,377	$578,974	$85,429	$108,949	$320,428	$493,544	2060	2060

* not breakeven

Table XI-6
Breakeven Analysis for **$5.3 Million VSLs**
(@7 Percent Discount**,** 2014 $ in Millions**)**

	Calendar	Cumulative Monetized Benefits		Total Cumulative Annual Costs		Cumulative Net Benefits		Breakeven Year	
Year	Year	Low	High	Low	High	Low	High	Low	High
1	2021	$0	$0	$2,119	$2,768	-$2,768	-$2,119	*	*
2	2022	$11	$15	$4,840	$6,316	-$6,305	-$4,825	*	*
3	2023	$81	$106	$8,076	$10,492	-$10,412	-$7,970	*	*
4	2024	$335	$439	$11,028	$14,423	-$14,087	-$10,588	*	*
5	2025	$939	$1,232	$13,757	$17,965	-$17,026	-$12,525	*	*
6	2026	$2,132	$2,802	$16,277	$21,228	-$19,096	-$13,475	*	*
7	2027	$4,141	$5,454	$18,622	$24,260	-$20,118	-$13,168	*	*
8	2028	$7,038	$9,288	$20,810	$27,083	-$20,045	-$11,522	*	*
9	2029	$10,796	$14,274	$22,847	$29,709	-$18,913	-$8,573	*	*
10	2030	$15,367	$20,352	$24,766	$32,176	-$16,809	-$4,414	*	*
11	2031	$20,684	$27,434	$26,564	$34,485	-$13,801	$870	*	2031
12	2032	$26,661	$35,409	$28,246	$36,643	-$9,982	$7,163	*	2032
13	2033	$33,201	$44,147	$29,819	$38,660	-$5,460	$14,328	*	2033
14	2034	$40,203	$53,517	$31,297	$40,554	-$350	$22,221	*	2034
15	2035	$47,560	$63,375	$32,690	$42,337	$5,223	$30,685	2035	2035
16	2036	$55,163	$73,575	$33,991	$43,995	$11,169	$39,584	2036	2036
17	2037	$62,907	$83,975	$35,214	$45,542	$17,364	$48,761	2037	2037
18	2038	$70,688	$94,438	$36,361	$46,992	$23,697	$58,077	2038	2038
19	2039	$78,416	$104,839	$37,439	$48,381	$30,035	$67,399	2039	2039
20	2040	$86,009	$115,070	$38,463	$49,676	$36,334	$76,607	2040	2040
21	2041	$93,403	$125,040	$39,427	$50,893	$42,510	$85,614	2041	2041
22	2042	$100,543	$134,678	$40,299	$51,994	$48,550	$94,378	2042	2042
23	2043	$107,394	$143,932	$41,116	$53,023	$54,371	$102,815	2043	2043
24	2044	$113,934	$152,771	$41,881	$53,986	$59,948	$110,890	2044	2044
25	2045	$120,154	$161,183	$42,605	$54,894	$65,260	$118,578	2045	2045
26	2046	$126,050	$169,159	$43,276	$55,738	$70,312	$125,883	2046	2046
27	2047	$131,631	$176,712	$43,905	$56,528	$75,103	$132,806	2047	2047
28	2048	$136,903	$183,848	$44,495	$57,267	$79,636	$139,354	2048	2048
29	2049	$141,877	$190,583	$45,047	$57,959	$83,918	$145,536	2049	2049
30	2050	$146,566	$196,933	$45,571	$58,614	$87,952	$151,361	2050	2050
31	2051	$150,978	$202,908	$46,057	$59,219	$91,759	$156,852	2051	2051
32	2052	$155,127	$208,528	$46,509	$59,780	$95,346	$162,019	2052	2052
33	2053	$159,022	$213,806	$46,931	$60,304	$98,719	$166,874	2053	2053
34	2054	$162,680	$218,762	$47,325	$60,803	$101,878	$171,436	2054	2054
35	2055	$166,110	$223,409	$47,697	$61,264	$104,846	$175,713	2055	2055
36	2056	$169,323	$227,763	$48,039	$61,691	$107,633	$179,725	2056	2056
37	2057	$172,333	$231,842	$48,358	$62,088	$110,245	$183,484	2057	2057
38	2058	$175,151	$235,661	$48,656	$62,459	$112,691	$187,005	2058	2058
39	2059	$177,785	$239,232	$48,934	$62,805	$114,980	$190,298	2059	2059
40	2060	$180,249	$242,572	$49,197	$63,131	$117,118	$193,375	2060	2060

* not breakeven

Cost-Effectiveness Analysis

Tables XI-7 and XI-8 show the cost-effectiveness analysis for the $5.3 million lower range VSL at a 3 percent and 7 percent discount rate, respectively. The proposed rule would be cost-effective between MY 2024 and MY 2027 vehicles at a 3 percent discount rate and MY 2025 and MY 2027 vehicles at a 7 percent discount rates. The cost-effectiveness was determined by comparing the net MY cost per fatal equivalent to the $5.6 million comprehensive cost of a fatality.

Table XI-7
Cost-Effectiveness Analysis for **$5.3 Million VSLs**
(**@3 Percent** Discount, 2014 $ in Millions)

Year	Model Year	Fatal Equivalents		MY Net Costs		Net Cost per Fatal Equivalent		Cost-Effective	
		Low	High	Low	High	Low	High	Low	High
1	2021	0.00	0.00	$2,221.39	$2,893.52	$2,221.39	$2,893.52	*	*
2	2022	3.94	77.10	$2,958.11	$3,963.34	$38.37	$1,005.62	*	*
3	2023	26.45	236.95	$3,592.36	$4,965.74	$15.16	$187.77	*	*
4	2024	118.15	659.03	$2,975.53	$4,884.16	$4.52	$41.34	2024	*
5	2025	291.76	1,155.55	$2,317.96	$4,491.28	$2.01	$15.39	2025	*
6	2026	664.58	2,016.59	$1,208.85	$3,970.64	$0.60	$5.97	2026	*
7	2027	1,260.15	2,978.41	$7.03	$3,221.61	$0.00	$2.56	2027	2027
8	2028	1,819.51	3,511.64	-$657.77	$2,530.40	-$0.19	$1.39	2028	2028
9	2029	2,204.73	3,693.58	-$896.40	$2,042.34	-$0.24	$0.93	2029	2029
10	2030	2,551.73	3,880.28	-$1,101.36	$1,645.84	-$0.28	$0.64	2030	2030
11	2031	2,858.85	4,048.85	-$1,301.00	$1,280.31	-$0.32	$0.45	2031	2031
12	2032	3,128.83	4,201.15	-$1,487.91	$952.38	-$0.35	$0.30	2032	2032
13	2033	3,226.33	4,517.01	-$1,876.58	$833.11	-$0.42	$0.26	2033	2033
14	2034	3,324.51	4,819.15	-$2,233.79	$731.05	-$0.46	$0.22	2034	2034
15	2035	3,409.73	5,084.38	-$2,526.26	$664.36	-$0.50	$0.19	2035	2035
16	2036	3,483.65	5,315.58	-$2,816.23	$547.13	-$0.53	$0.16	2036	2036
17	2037	3,551.23	5,520.38	-$3,048.91	$459.30	-$0.55	$0.13	2037	2037
18	2038	3,605.14	5,688.76	-$3,242.04	$402.76	-$0.57	$0.11	2038	2038
19	2039	3,653.77	5,839.42	-$3,409.01	$463.44	-$0.58	$0.13	2039	2039
20	2040	3,704.16	5,984.75	-$3,527.55	$387.12	-$0.59	$0.10	2040	2040
21	2041	3,762.54	6,140.22	-$3,692.67	$345.44	-$0.60	$0.09	2041	2041
22	2042	3,653.63	6,002.35	-$3,646.00	$315.00	-$0.61	$0.09	2042	2042
23	2043	3,672.90	6,060.75	-$3,711.27	$294.44	-$0.61	$0.08	2043	2043
24	2044	3,692.40	6,112.78	-$3,768.41	$274.41	-$0.62	$0.07	2044	2044
25	2045	3,710.90	6,161.47	-$3,785.48	$292.50	-$0.61	$0.08	2045	2045
26	2046	3,728.30	6,204.73	-$3,865.08	$242.56	-$0.62	$0.07	2046	2046
27	2047	3,746.31	6,248.67	-$3,909.53	$228.66	-$0.63	$0.06	2047	2047
28	2048	3,761.31	6,290.15	-$3,952.52	$216.58	-$0.63	$0.06	2048	2048
29	2049	3,776.63	6,329.47	-$3,992.64	$204.60	-$0.63	$0.05	2049	2049

30	2050	3,795.70	6,371.80	-$3,984.67	$240.58	-$0.63	$0.06	2050	2050

* not cost-effective

Table XI-8
Cost-Effectiveness Analysis for **$5.3 Million VSLs**
(**@7 Percent** Discount, 2014 $ in Millions)

Year	Model Year	Fatal Equivalents		MY Net Costs		Net Cost per Fatal Equivalent		Cost-Effective	
		Low	High	Low	High	Low	High	Low	High
1	2021	0.00	0.00	$2,213.68	$2,885.80	$2,213.68	$2,885.80	*	*
2	2022	3.71	58.15	$2,969.81	$3,952.00	$51.07	$1,065.28	*	*
3	2023	24.73	181.27	$3,645.47	$4,952.42	$20.11	$200.26	*	*
4	2024	109.14	511.48	$3,141.76	$4,879.71	$6.14	$44.71	*	*
5	2025	266.02	903.85	$2,612.54	$4,507.19	$2.89	$16.94	2025	*
6	2026	597.64	1,586.81	$1,722.09	$4,035.73	$1.09	$6.75	2026	*
7	2027	1,120.37	2,360.44	$751.28	$3,373.91	$0.32	$3.01	2027	2027
8	2028	1,605.14	2,794.00	$208.58	$2,771.96	$0.07	$1.73	2028	2028
9	2029	1,937.44	2,952.77	-$2.00	$2,347.17	$0.00	$1.21	2029	2029
10	2030	2,237.25	3,114.73	-$177.05	$2,006.97	-$0.06	$0.90	2030	2030
11	2031	2,434.80	3,348.54	-$458.15	$1,772.63	-$0.14	$0.73	2031	2031
12	2032	2,530.21	3,667.39	-$850.33	$1,654.44	-$0.23	$0.65	2032	2032
13	2033	2,616.61	3,952.21	-$1,200.35	$1,548.14	-$0.30	$0.59	2033	2033
14	2034	2,702.68	4,217.09	-$1,512.27	$1,460.19	-$0.36	$0.54	2034	2034
15	2035	2,777.85	4,449.39	-$1,764.75	$1,405.16	-$0.40	$0.51	2035	2035
16	2036	2,842.71	4,652.61	-$2,020.80	$1,298.41	-$0.43	$0.46	2036	2036
17	2037	2,902.73	4,834.31	-$2,225.59	$1,219.23	-$0.46	$0.42	2037	2037
18	2038	2,948.81	4,981.77	-$2,393.47	$1,171.68	-$0.48	$0.40	2038	2038
19	2039	2,991.19	5,114.05	-$2,538.36	$1,239.43	-$0.50	$0.41	2039	2039
20	2040	3,034.19	5,241.45	-$2,635.41	$1,171.48	-$0.50	$0.39	2040	2040
21	2041	3,082.80	5,374.55	-$2,773.58	$1,141.05	-$0.52	$0.37	2041	2041
22	2042	2,992.91	5,254.29	-$2,748.24	$1,088.07	-$0.52	$0.36	2042	2042
23	2043	3,010.03	5,306.13	-$2,805.80	$1,069.77	-$0.53	$0.36	2043	2043
24	2044	3,025.69	5,350.12	-$2,853.41	$1,054.05	-$0.53	$0.35	2044	2044
25	2045	3,042.72	5,393.44	-$2,864.22	$1,073.57	-$0.53	$0.35	2045	2045
26	2046	3,055.21	5,430.11	-$2,936.06	$1,029.21	-$0.54	$0.34	2046	2046
27	2047	3,071.91	5,470.54	-$2,976.53	$1,016.55	-$0.54	$0.33	2047	2047
28	2048	3,083.97	5,504.91	-$3,011.12	$1,007.69	-$0.55	$0.33	2048	2048
29	2049	3,098.02	5,537.38	-$3,043.14	$996.93	-$0.55	$0.32	2049	2049
30	2050	3,112.44	5,573.77	-$3,028.20	$1,038.18	-$0.54	$0.33	2050	2050

* not cost-effective

Net-Benefit Analysis

Tables XI-9 and XI-10 show the discounted net-benefit for the $5.3 million VSL at 3 percent and 7 percent, respectively. With the $5.3 million lower range VSL, the proposed rule would accrue positive benefits cost-effective between MY 2025 and MY 2027 vehicles for both discount rates.

Table XI-9
Net-Benefit Analysis for **$5.3 Million VSLs**
(**@3 Percent** Discount, 2014 $ in Millions)

Year	Model Year	Net Benefits		MY with Positive Net Befits	
		Low	High	Low	High
1	2021	-$2,893.5	-$2,221.4	*	*
2	2022	-$3,946.1	-$2,622.1	*	*
3	2023	-$4,849.7	-$2,559.8	*	*
4	2024	-$4,365.9	-$103.6	*	*
5	2025	-$3,211.4	$2,717.9	*	2025
6	2026	-$1,055.5	$7,579.8	*	2026
7	2027	$2,305.9	$12,973.8	2027	2027
8	2028	$5,450.6	$15,963.1	2028	2028
9	2029	$7,628.2	$16,995.2	2029	2029
10	2030	$9,546.6	$18,014.4	2030	2030
11	2031	$11,259.2	$18,949.2	2031	2031
12	2032	$12,771.0	$19,800.3	2032	2032
13	2033	$13,317.8	$21,565.4	2033	2033
14	2034	$13,850.4	$23,240.1	2034	2034
15	2035	$14,290.8	$24,689.2	2035	2035
16	2036	$14,732.2	$25,987.5	2036	2036
17	2037	$15,116.4	$27,113.4	2037	2037
18	2038	$15,409.3	$28,041.0	2038	2038
19	2039	$15,561.8	$28,865.2	2039	2039
20	2040	$15,859.1	$29,617.7	2040	2040
21	2041	$16,156.8	$30,461.0	2041	2041
22	2042	$15,709.5	$29,813.6	2042	2042
23	2043	$15,814.5	$30,133.7	2043	2043
24	2044	$15,920.1	$30,417.9	2044	2044
25	2045	$15,983.1	$30,647.4	2045	2045
26	2046	$16,109.3	$30,915.8	2046	2046
27	2047	$16,202.2	$31,151.9	2047	2047
28	2048	$16,280.0	$31,375.8	2048	2048
29	2049	$16,359.2	$31,587.5	2049	2049
30	2050	$16,406.8	$31,764.1	2050	2050

*MY vehicles with negative net benefits

Table XI-10
Net-Benefit Analysis for **$5.3 Million VSLs**
(**@7 Percent** Discount, 2014 $ in Millions)

Year	Model Year	Net Benefits		MY With Positive Net Befits	
		Low	High	Low	High
1	2021	-$2,885.8	-$2,213.7	*	*
2	2022	-$3,935.7	-$2,716.4	*	*
3	2023	-$4,843.9	-$2,855.6	*	*
4	2024	-$4,401.0	-$912.9	*	*
5	2025	-$3,340.3	$1,326.3	*	2025
6	2026	-$1,414.2	$5,193.3	*	2026
7	2027	$1,540.5	$9,536.0	2027	2027
8	2028	$4,268.8	$11,968.7	2028	2028
9	2029	$6,151.0	$12,871.6	2029	2029
10	2030	$7,806.2	$13,753.0	2030	2030
11	2031	$8,906.8	$15,052.9	2031	2031
12	2032	$9,443.4	$16,835.2	2032	2032
13	2033	$9,928.6	$18,427.1	2033	2033
14	2034	$10,394.0	$19,894.1	2034	2034
15	2035	$10,778.6	$21,159.6	2035	2035
16	2036	$11,169.8	$22,302.0	2036	2036
17	2037	$11,512.1	$23,299.2	2037	2037
18	2038	$11,761.7	$24,110.3	2038	2038
19	2039	$11,879.8	$24,832.3	2039	2039
20	2040	$12,136.3	$25,485.1	2040	2040
21	2041	$12,379.9	$26,203.8	2041	2041
22	2042	$12,038.6	$25,654.5	2042	2042
23	2043	$12,131.9	$25,938.3	2043	2043
24	2044	$12,216.3	$26,177.9	2044	2044
25	2045	$12,271.4	$26,377.8	2045	2045
26	2046	$12,370.6	$26,609.6	2046	2046
27	2047	$12,456.5	$26,826.4	2047	2047
28	2048	$12,518.2	$27,011.0	2048	2048
29	2049	$12,590.6	$27,184.6	2049	2049
30	2050	$12,612.6	$27,328.4	2050	2050

*MY vehicles with negative benefits

B. Impacts of $13.2 Million VSL

<u>Monetized Annual Benefits</u>

Table XI-11 shows the fatal equivalents and monetized annual benefits of the proposed for the alternative VSL of $13.2 million. With this VSL value, the proposed rule would save $25.3 to $33.0 million in 2022 and $72.2 to $97.5 billion in 2060. These savings are 31.9 percent more than the primary estimates.

Table XI-11
Annual Monetized Benefits of the Proposed Rule for **$13.2 Million VSLs**
(Undiscounted, 2014 $ in Millions)

Year	Calendar Year	Fatal Equivalents		Total Monetized Benefits	
		Low	High	Low	High
1	2021	0.00	0.00	$0.0	$0.0
2	2022	1.88	2.44	$25.3	$33.0
3	2023	12.32	16.09	$166.5	$217.2
4	2024	48.36	63.12	$653.2	$852.5
5	2025	122.84	160.53	$1,659.0	$2,168.1
6	2026	259.57	340.02	$3,505.7	$4,592.2
7	2027	467.77	614.61	$6,317.5	$8,300.7
8	2028	721.69	951.03	$9,746.9	$12,844.3
9	2029	1,001.66	1,323.32	$13,528.0	$17,872.4
10	2030	1,303.80	1,726.02	$17,608.7	$23,311.1
11	2031	1,622.48	2,151.99	$21,912.7	$29,064.0
12	2032	1,951.43	2,592.60	$26,355.3	$35,014.7
13	2033	2,284.75	3,040.08	$30,857.0	$41,058.3
14	2034	2,617.22	3,487.45	$35,347.2	$47,100.3
15	2035	2,942.56	3,926.26	$39,741.2	$53,026.6
16	2036	3,253.55	4,346.66	$43,941.3	$58,704.5
17	2037	3,545.25	4,741.94	$47,880.9	$64,043.0
18	2038	3,812.98	5,105.64	$51,496.8	$68,955.1
19	2039	4,051.12	5,430.28	$54,713.1	$73,339.5
20	2040	4,259.56	5,715.44	$57,528.1	$77,190.8
21	2041	4,437.62	5,960.02	$59,933.0	$80,493.9
22	2042	4,584.93	6,163.15	$61,922.4	$83,237.4
23	2043	4,707.50	6,332.84	$63,577.8	$85,529.1
24	2044	4,809.09	6,473.78	$64,949.9	$87,432.7
25	2045	4,892.53	6,589.65	$66,076.8	$88,997.5
26	2046	4,963.15	6,687.66	$67,030.6	$90,321.2
27	2047	5,025.24	6,773.58	$67,869.1	$91,481.7
28	2048	5,079.99	6,849.10	$68,608.6	$92,501.5
29	2049	5,129.14	6,916.77	$69,272.4	$93,415.5
30	2050	5,172.69	6,976.59	$69,860.5	$94,223.4
31	2051	5,208.62	7,026.08	$70,345.8	$94,891.8
32	2052	5,240.26	7,069.79	$70,773.2	$95,482.1
33	2053	5,266.30	7,105.83	$71,124.8	$95,968.9
34	2054	5,288.46	7,136.59	$71,424.1	$96,384.3
35	2055	5,307.02	7,162.34	$71,674.8	$96,732.1
36	2056	5,322.64	7,184.03	$71,885.7	$97,025.1
37	2057	5,333.98	7,199.95	$72,038.8	$97,240.0
38	2058	5,340.10	7,208.87	$72,121.6	$97,360.5
39	2059	5,344.08	7,214.90	$72,175.4	$97,441.9
40	2060	5,346.07	7,218.09	$72,202.2	$97,485.0

Monetized MY Benefits

Tables XI-12 and XI-13 present monetized MY benefits at a 3 percent and 7 percent discount rate, respectively. The monetized benefits per MY vehicles would range $44.6 to $869.0 million for MY 2022 vehicles and $43.0 to $71.8 billion for MY 2050 vehicles at a 3 percent discount rate. At a 7 percent discount rate, the savings would be $42.0 to $655.4 million for MY 2022 vehicles and $35.2 to $62.8 billion for MY 2050 vehicles. These savings are 31.9 percent more than the primary estimates.

Table XI-12
Monetized MY Benefits for **$13.2 Million VSLs**
(**@3 Percent** Discount, 2014 $ in Millions)

Year	Model Year	Fatal Equivalents Low	Fatal Equivalents High	Total Monetized Benefits Low	Total Monetized Benefits High
1	2021	0.00	0.00	$0.0	$0.0
2	2022	3.30	64.34	$44.6	$869.0
3	2023	22.17	197.73	$299.4	$2,670.4
4	2024	99.04	549.94	$1,337.6	$7,427.4
5	2025	244.55	964.29	$3,302.8	$13,023.3
6	2026	557.01	1,682.82	$7,522.8	$22,727.6
7	2027	1,056.13	2,485.46	$14,263.8	$33,567.7
8	2028	1,524.89	2,930.45	$20,594.6	$39,577.6
9	2029	1,847.68	3,082.29	$24,954.1	$41,628.3
10	2030	2,138.44	3,238.10	$28,881.0	$43,732.7
11	2031	2,395.77	3,378.78	$32,356.4	$45,632.6
12	2032	2,621.89	3,505.88	$35,410.3	$47,349.3
13	2033	2,703.56	3,769.46	$36,513.3	$50,909.1
14	2034	2,785.80	4,021.61	$37,624.0	$54,314.5
15	2035	2,857.17	4,242.96	$38,588.0	$57,304.0
16	2036	2,919.09	4,435.92	$39,424.2	$59,910.0
17	2037	2,975.69	4,606.83	$40,188.6	$62,218.3
18	2038	3,020.83	4,747.37	$40,798.3	$64,116.3
19	2039	3,061.55	4,873.10	$41,348.2	$65,814.4
20	2040	3,103.75	4,994.39	$41,918.1	$67,452.5
21	2041	3,152.64	5,124.15	$42,578.5	$69,205.0
22	2042	3,061.37	5,009.10	$41,345.8	$67,651.2
23	2043	3,077.50	5,057.84	$41,563.6	$68,309.4
24	2044	3,093.83	5,101.26	$41,784.2	$68,895.9
25	2045	3,109.31	5,141.90	$41,993.3	$69,444.8
26	2046	3,123.89	5,178.01	$42,190.1	$69,932.4
27	2047	3,138.97	5,214.68	$42,393.8	$70,427.7
28	2048	3,151.53	5,249.30	$42,563.5	$70,895.2
29	2049	3,164.36	5,282.12	$42,736.8	$71,338.4
30	2050	3,180.34	5,317.44	$42,952.5	$71,815.6

Table XI-13
Monetized MY Benefits for **$13.2 Million VSLs**
(**@7 Percen**t Discount, 2014 $ in Millions)

Year	Model Year	Fatal Equivalents		Total Monetized Benefits	
		Low	High	Low	High
1	2021	0.00	0.00	$0.0	$0.0
2	2022	3.11	48.53	$42.0	$655.4
3	2023	20.73	151.27	$279.9	$2,043.0
4	2024	91.48	426.82	$1,235.5	$5,764.5
5	2025	222.97	754.25	$3,011.4	$10,186.6
6	2026	500.91	1,324.17	$6,765.1	$17,883.8
7	2027	938.99	1,969.76	$12,681.7	$26,603.0
8	2028	1,345.24	2,331.58	$18,168.3	$31,489.4
9	2029	1,623.69	2,464.08	$21,929.0	$33,279.0
10	2030	1,874.90	2,599.24	$25,321.8	$35,104.4
11	2031	2,040.36	2,794.35	$27,556.4	$37,739.5
12	2032	2,120.28	3,060.44	$28,635.8	$41,333.2
13	2033	2,192.65	3,298.13	$29,613.2	$44,543.4
14	2034	2,264.75	3,519.19	$30,587.0	$47,528.9
15	2035	2,327.71	3,713.05	$31,437.3	$50,147.2
16	2036	2,382.03	3,882.65	$32,170.9	$52,437.8
17	2037	2,432.30	4,034.29	$32,849.8	$54,485.8
18	2038	2,470.89	4,157.36	$33,370.9	$56,147.9
19	2039	2,506.37	4,267.76	$33,850.2	$57,639.0
20	2040	2,542.39	4,374.09	$34,336.6	$59,074.9
21	2041	2,583.09	4,485.17	$34,886.4	$60,575.2
22	2042	2,507.76	4,384.82	$33,869.0	$59,219.9
23	2043	2,522.09	4,428.09	$34,062.5	$59,804.3
24	2044	2,535.20	4,464.80	$34,239.5	$60,300.1
25	2045	2,549.46	4,500.96	$34,432.1	$60,788.4
26	2046	2,559.92	4,531.57	$34,573.4	$61,201.8
27	2047	2,573.91	4,565.31	$34,762.3	$61,657.4
28	2048	2,584.01	4,593.99	$34,898.7	$62,044.9
29	2049	2,595.77	4,621.09	$35,057.6	$62,410.9
30	2050	2,607.85	4,651.47	$35,220.8	$62,821.1

Breakeven Analysis

Table XI-14 and XI-15 show the results from the breakeven analysis. With the $13.2 million upper range VSL, the propose rule would reach the breakeven year between 2029 to 2030 for a 3 percent discount rate and 2029 to 2031 for a 7 percent discount rate, as shown in Table XI-5. As a result, the breakeven year would be two years earlier than the breakeven year that was estimated in the main analysis using $9.4 million VSL.

Table XI-14
Breakeven Analysis for **$13.2 Million VSLs**
(@3 Percent Discount**,** 2014 $ in Millions**)**

		Cumulative Monetized Benefits		Total Cumulative Annual Costs		Cumulative Net Benefits		Breakeven Year	
Year	Calendar Year	Low	High	Low	High	Low	High	Low	High
1	2021	$0	$0	$2,160	$2,822	-$2,822	-$2,160	*	*
2	2022	$24	$32	$5,040	$6,578	-$6,554	-$5,009	*	*
3	2023	$179	$233	$8,600	$11,172	-$10,993	-$8,366	*	*
4	2024	$768	$1,002	$11,973	$15,663	-$14,895	-$10,971	*	*
5	2025	$2,220	$2,900	$15,213	$19,868	-$17,647	-$12,313	*	*
6	2026	$5,200	$6,804	$18,320	$23,892	-$18,692	-$11,517	*	*
7	2027	$10,413	$13,653	$21,324	$27,775	-$17,362	-$7,671	*	*
8	2028	$18,223	$23,944	$24,236	$31,533	-$13,310	-$292	*	*
9	2029	$28,745	$37,845	$27,053	$35,164	-$6,419	$10,792	*	2029
10	2030	$42,043	$55,450	$29,809	$38,707	$3,336	$25,641	2030	2030
11	2031	$58,109	$76,760	$32,492	$42,152	$15,957	$44,267	2031	2031
12	2032	$76,869	$101,683	$35,099	$45,497	$31,372	$66,584	2032	2032
13	2033	$98,194	$130,058	$37,632	$48,744	$49,450	$92,427	2033	2033
14	2034	$121,912	$161,663	$40,102	$51,911	$70,001	$121,560	2034	2034
15	2035	$147,799	$196,204	$42,524	$55,009	$92,790	$153,681	2035	2035
16	2036	$175,588	$233,329	$44,872	$58,001	$117,587	$188,457	2036	2036
17	2037	$204,987	$272,651	$47,165	$60,903	$144,084	$225,487	2037	2037
18	2038	$235,684	$313,755	$49,400	$63,726	$171,958	$264,356	2038	2038
19	2039	$267,352	$356,204	$51,581	$66,537	$200,815	$304,623	2039	2039
20	2040	$299,677	$399,578	$53,734	$69,259	$230,418	$345,844	2040	2040
21	2041	$332,376	$443,495	$55,837	$71,918	$260,459	$387,658	2041	2041
22	2042	$365,177	$487,586	$57,817	$74,415	$290,762	$429,769	2042	2042
23	2043	$397,868	$531,565	$59,742	$76,841	$321,027	$471,823	2043	2043
24	2044	$430,298	$575,220	$61,616	$79,200	$351,098	$513,605	2044	2044
25	2045	$462,325	$618,357	$63,455	$81,509	$380,816	$554,902	2045	2045
26	2046	$493,870	$660,863	$65,229	$83,738	$410,132	$595,633	2046	2046
27	2047	$524,879	$702,661	$66,956	$85,906	$438,974	$635,704	2047	2047
28	2048	$555,314	$743,694	$68,637	$88,014	$467,300	$675,057	2048	2048
29	2049	$585,150	$783,928	$70,273	$90,063	$495,087	$713,656	2049	2049
30	2050	$614,358	$823,323	$71,886	$92,078	$522,281	$751,437	2050	2050
31	2051	$642,912	$861,840	$73,437	$94,010	$548,902	$788,403	2051	2051
32	2052	$670,804	$899,469	$74,940	$95,875	$574,928	$824,529	2052	2052
33	2053	$698,016	$936,187	$76,396	$97,681	$600,335	$859,791	2053	2053
34	2054	$724,550	$971,994	$77,806	$99,468	$625,082	$894,187	2054	2054
35	2055	$750,403	$1,006,885	$79,189	$101,187	$649,216	$927,696	2055	2055
36	2056	$775,577	$1,040,863	$80,513	$102,837	$672,741	$960,350	2056	2056
37	2057	$800,071	$1,073,925	$81,797	$104,435	$695,636	$992,128	2057	2057
38	2058	$823,878	$1,106,063	$83,040	$105,982	$717,896	$1,023,023	2058	2058
39	2059	$847,010	$1,137,294	$84,246	$107,481	$739,529	$1,053,048	2059	2059

40	2060	$869,472	$1,167,621	$85,429	$108,949	$760,524	$1,082,192	2060	2060

*not breakeven

Table XI-15
Breakeven Analysis for **$13.2 Million VSLs**
(@7 Percent Discount**,** 2014 $ in Millions**)**

Year	Calendar Year	Cumulative Monetized Benefits		Total Cumulative Annual Costs		Cumulative Net Benefits		Breakeven Year	
		Low	High	Low	High	Low	High	Low	High
1	2021	$0	$0	$2,119	$2,768	-$2,768	-$2,119	*	*
2	2022	$23	$30	$4,840	$6,316	-$6,293	-$4,810	*	*
3	2023	$163	$213	$8,076	$10,492	-$10,329	-$7,862	*	*
4	2024	$679	$886	$11,028	$14,423	-$13,744	-$10,142	*	*
5	2025	$1,902	$2,485	$13,757	$17,965	-$16,063	-$11,272	*	*
6	2026	$4,319	$5,650	$16,277	$21,228	-$16,910	-$10,626	*	*
7	2027	$8,389	$10,998	$18,622	$24,260	-$15,871	-$7,624	*	*
8	2028	$14,256	$18,730	$20,810	$27,083	-$12,827	-$2,080	*	*
9	2029	$21,867	$28,785	$22,847	$29,709	-$7,842	$5,938	*	2029
10	2030	$31,126	$41,042	$24,766	$32,176	-$1,051	$16,276	*	2030
11	2031	$41,894	$55,324	$26,564	$34,485	$7,408	$28,760	2031	2031
12	2032	$53,999	$71,406	$28,246	$36,643	$17,355	$43,160	2032	2032
13	2033	$67,242	$89,028	$29,819	$38,660	$28,582	$59,209	2033	2033
14	2034	$81,424	$107,925	$31,297	$40,554	$40,870	$76,628	2034	2034
15	2035	$96,323	$127,805	$32,690	$42,337	$53,986	$95,115	2035	2035
16	2036	$111,720	$148,375	$33,991	$43,995	$67,725	$114,383	2036	2036
17	2037	$127,401	$169,349	$35,214	$45,542	$81,858	$134,135	2037	2037
18	2038	$143,159	$190,449	$36,361	$46,992	$96,167	$154,088	2038	2038
19	2039	$158,807	$211,424	$37,439	$48,381	$110,426	$173,985	2039	2039
20	2040	$174,184	$232,057	$38,463	$49,676	$124,508	$193,594	2040	2040
21	2041	$189,155	$252,165	$39,427	$50,893	$138,262	$212,738	2041	2041
22	2042	$203,614	$271,601	$40,299	$51,994	$151,620	$231,301	2042	2042
23	2043	$217,487	$290,263	$41,116	$53,023	$164,463	$249,147	2043	2043
24	2044	$230,730	$308,091	$41,881	$53,986	$176,744	$266,209	2044	2044
25	2045	$243,324	$325,053	$42,605	$54,894	$188,430	$282,449	2045	2045
26	2046	$255,262	$341,140	$43,276	$55,738	$199,524	$297,864	2046	2046
27	2047	$266,563	$356,371	$43,905	$56,528	$210,035	$312,466	2047	2047
28	2048	$277,238	$370,765	$44,495	$57,267	$219,971	$326,270	2048	2048
29	2049	$287,310	$384,347	$45,047	$57,959	$229,351	$339,300	2049	2049
30	2050	$296,804	$397,152	$45,571	$58,614	$238,190	$351,581	2050	2050
31	2051	$305,738	$409,203	$46,057	$59,219	$246,520	$363,147	2051	2051
32	2052	$314,139	$420,537	$46,509	$59,780	$254,359	$374,028	2052	2052
33	2053	$322,027	$431,180	$46,931	$60,304	$261,723	$384,249	2053	2053
34	2054	$329,434	$441,175	$47,325	$60,803	$268,631	$393,850	2054	2054
35	2055	$336,379	$450,549	$47,697	$61,264	$275,114	$402,852	2055	2055
36	2056	$342,884	$459,329	$48,039	$61,691	$281,194	$411,290	2056	2056
37	2057	$348,979	$467,556	$48,358	$62,088	$286,891	$419,198	2057	2057
38	2058	$354,684	$475,257	$48,656	$62,459	$292,225	$426,601	2058	2058
39	2059	$360,018	$482,458	$48,934	$62,805	$297,213	$433,524	2059	2059
40	2060	$365,007	$489,194	$49,197	$63,131	$301,876	$439,997	2060	2060

*not breakeven

Cost-Effectiveness Analysis

Tables XI-16 and XI-17 show the cost-effectiveness analysis used to determine the MY vehicles that would be cost-effective. A MY vehicle is cost-effective if its net MY cost per fatal equivalent is less than the $13.5 million comprehensive cost of a fatality. As shown, the proposed rule would be cost-effective between MY 2024 and MY 2026 vehicles for both discount rates. Note that no life would be saved for MY 2021 vehicles. The net MY cost per fatal equivalent for MY 2021 is the net cost for that year.

Table XI-16
Cost-Effectiveness Analysis for **$13.2 Million VSLs**
(**@3 Percent** Discount, 2014 $ in Millions)

Year	Model Year	Fatal Equivalents		MY Net Costs		Net MY Cost per Fatal Equivalent		Cost-Effective	
		Low	High	Low	High	Low	High	Low	High
1	2021	0.00	0.00	$2,221.39	$2,893.52	$2,221.39	$2,893.52	*	*
2	2022	3.30	64.34	$2,958.11	$3,963.34	$45.98	$1,199.71	*	*
3	2023	22.17	197.73	$3,592.36	$4,965.74	$18.17	$224.02	*	*
4	2024	99.04	549.94	$2,975.53	$4,884.16	$5.41	$49.32	2024	*
5	2025	244.55	964.29	$2,317.96	$4,491.28	$2.40	$18.37	2025	*
6	2026	557.01	1,682.82	$1,208.85	$3,970.64	$0.72	$7.13	2026	2026
7	2027	1,056.13	2,485.46	$7.03	$3,221.61	$0.00	$3.05	2027	2027
8	2028	1,524.89	2,930.45	-$657.77	$2,530.40	-$0.22	$1.66	2028	2028
9	2029	1,847.68	3,082.29	-$896.40	$2,042.34	-$0.29	$1.11	2029	2029
10	2030	2,138.44	3,238.10	-$1,101.36	$1,645.84	-$0.34	$0.77	2030	2030
11	2031	2,395.77	3,378.78	-$1,301.00	$1,280.31	-$0.39	$0.53	2031	2031
12	2032	2,621.89	3,505.88	-$1,487.91	$952.38	-$0.42	$0.36	2032	2032
13	2033	2,703.56	3,769.46	-$1,876.58	$833.11	-$0.50	$0.31	2033	2033
14	2034	2,785.80	4,021.61	-$2,233.79	$731.05	-$0.56	$0.26	2034	2034
15	2035	2,857.17	4,242.96	-$2,526.26	$664.36	-$0.60	$0.23	2035	2035
16	2036	2,919.09	4,435.92	-$2,816.23	$547.13	-$0.63	$0.19	2036	2036
17	2037	2,975.69	4,606.83	-$3,048.91	$459.30	-$0.66	$0.15	2037	2037
18	2038	3,020.83	4,747.37	-$3,242.04	$402.76	-$0.68	$0.13	2038	2038
19	2039	3,061.55	4,873.10	-$3,409.01	$463.44	-$0.70	$0.15	2039	2039
20	2040	3,103.75	4,994.39	-$3,527.55	$387.12	-$0.71	$0.12	2040	2040
21	2041	3,152.64	5,124.15	-$3,692.67	$345.44	-$0.72	$0.11	2041	2041
22	2042	3,061.37	5,009.10	-$3,646.00	$315.00	-$0.73	$0.10	2042	2042
23	2043	3,077.50	5,057.84	-$3,711.27	$294.44	-$0.73	$0.10	2043	2043
24	2044	3,093.83	5,101.26	-$3,768.41	$274.41	-$0.74	$0.09	2044	2044
25	2045	3,109.31	5,141.90	-$3,785.48	$292.50	-$0.74	$0.09	2045	2045
26	2046	3,123.89	5,178.01	-$3,865.08	$242.56	-$0.75	$0.08	2046	2046
27	2047	3,138.97	5,214.68	-$3,909.53	$228.66	-$0.75	$0.07	2047	2047
28	2048	3,151.53	5,249.30	-$3,952.52	$216.58	-$0.75	$0.07	2048	2048
29	2049	3,164.36	5,282.12	-$3,992.64	$204.60	-$0.76	$0.06	2049	2049

30	2050	3,180.34	5,317.44	-$3,984.67	$240.58	-$0.75	$0.08	2050	2050

*not cost-effective

Table XI-17
Cost-Effectiveness Analysis for **$13.3 Million VSLs**
(**@7 Percent** Discount, 2014 $ in Millions)

Year	Model Year	Fatal Equivalents		MY Net Costs		Net Cost per Fatal Equivalent		Cost-Effective	
		Low	High	Low	High	Low	High	Low	High
1	2021	0.00	0.00	$2,213.68	$2,885.80	$2,213.68	$2,885.80	*	*
2	2022	3.11	48.53	$2,969.81	$3,952.00	$61.20	$1,270.88	*	*
3	2023	20.73	151.27	$3,645.47	$4,952.42	$24.10	$238.93	*	*
4	2024	91.48	426.82	$3,141.76	$4,879.71	$7.36	$53.34	2024	*
5	2025	222.97	754.25	$2,612.54	$4,507.19	$3.46	$20.21	2025	*
6	2026	500.91	1,324.17	$1,722.09	$4,035.73	$1.30	$8.06	2026	2026
7	2027	938.99	1,969.76	$751.28	$3,373.91	$0.38	$3.59	2027	2027
8	2028	1,345.24	2,331.58	$208.58	$2,771.96	$0.09	$2.06	2028	2028
9	2029	1,623.69	2,464.08	-$2.00	$2,347.17	$0.00	$1.45	2029	2029
10	2030	1,874.90	2,599.24	-$177.05	$2,006.97	-$0.07	$1.07	2030	2030
11	2031	2,040.36	2,794.35	-$458.15	$1,772.63	-$0.16	$0.87	2031	2031
12	2032	2,120.28	3,060.44	-$850.33	$1,654.44	-$0.28	$0.78	2032	2032
13	2033	2,192.65	3,298.13	-$1,200.35	$1,548.14	-$0.36	$0.71	2033	2033
14	2034	2,264.75	3,519.19	-$1,512.27	$1,460.19	-$0.43	$0.64	2034	2034
15	2035	2,327.71	3,713.05	-$1,764.75	$1,405.16	-$0.48	$0.60	2035	2035
16	2036	2,382.03	3,882.65	-$2,020.80	$1,298.41	-$0.52	$0.55	2036	2036
17	2037	2,432.30	4,034.29	-$2,225.59	$1,219.23	-$0.55	$0.50	2037	2037
18	2038	2,470.89	4,157.36	-$2,393.47	$1,171.68	-$0.58	$0.47	2038	2038
19	2039	2,506.37	4,267.76	-$2,538.36	$1,239.43	-$0.59	$0.49	2039	2039
20	2040	2,542.39	4,374.09	-$2,635.41	$1,171.48	-$0.60	$0.46	2040	2040
21	2041	2,583.09	4,485.17	-$2,773.58	$1,141.05	-$0.62	$0.44	2041	2041
22	2042	2,507.76	4,384.82	-$2,748.24	$1,088.07	-$0.63	$0.43	2042	2042
23	2043	2,522.09	4,428.09	-$2,805.80	$1,069.77	-$0.63	$0.42	2043	2043
24	2044	2,535.20	4,464.80	-$2,853.41	$1,054.05	-$0.64	$0.42	2044	2044
25	2045	2,549.46	4,500.96	-$2,864.22	$1,073.57	-$0.64	$0.42	2045	2045
26	2046	2,559.92	4,531.57	-$2,936.06	$1,029.21	-$0.65	$0.40	2046	2046
27	2047	2,573.91	4,565.31	-$2,976.53	$1,016.55	-$0.65	$0.39	2047	2047
28	2048	2,584.01	4,593.99	-$3,011.12	$1,007.69	-$0.66	$0.39	2048	2048
29	2049	2,595.77	4,621.09	-$3,043.14	$996.93	-$0.66	$0.38	2049	2049
30	2050	2,607.85	4,651.47	-$3,028.20	$1,038.18	-$0.65	$0.40	2050	2050

*not cost-effective

Net-Benefit Analysis

Tables XI-18 and XI-19 show the net-benefit analysis for the $13.2 million VSL at a 3 percent and 7 percent discount rate, respectively. The proposed rule would accrue positive benefits cost-effective between MY 2024 and MY 2026 vehicles for both discount rates.

Table XI-18
Net-Benefit Analysis for **$13.2 Million VSLs**
(**@3 Percent** Discount, 2014 $ in Millions)

Year	Model Year	Net Benefits		MY with Positive Net Befits	
		Low	High	Low	High
1	2021	-$2,893.5	-$2,221.4	*	*
2	2022	-$3,923.5	-$2,184.0	*	*
3	2023	-$4,698.1	-$1,213.6	*	*
4	2024	-$3,688.6	$3,640.7	*	2024
5	2025	-$1,539.2	$9,283.3	*	2025
6	2026	$2,753.2	$19,037.3	2026	2026
7	2027	$9,527.2	$29,896.2	2027	2027
8	2028	$15,876.6	$35,915.4	2028	2028
9	2029	$20,260.9	$37,981.4	2029	2029
10	2030	$24,166.9	$40,061.5	2030	2030
11	2031	$27,638.5	$41,954.2	2031	2031
12	2032	$30,695.4	$43,670.8	2032	2032
13	2033	$31,800.3	$47,230.4	2033	2033
14	2034	$32,894.9	$50,622.0	2034	2034
15	2035	$33,823.0	$53,578.3	2035	2035
16	2036	$34,687.4	$56,190.5	2036	2036
17	2037	$35,458.3	$58,480.2	2037	2037
18	2038	$36,059.7	$60,364.8	2038	2038
19	2039	$36,490.4	$62,045.1	2039	2039
20	2040	$37,075.9	$63,623.5	2040	2040
21	2041	$37,707.7	$65,350.3	2041	2041
22	2042	$36,636.4	$63,919.7	2042	2042
23	2043	$36,851.6	$64,571.6	2043	2043
24	2044	$37,068.7	$65,151.6	2044	2044
25	2045	$37,237.4	$65,657.8	2045	2045
26	2046	$37,463.3	$66,172.1	2046	2046
27	2047	$37,659.2	$66,657.9	2047	2047
28	2048	$37,822.9	$67,117.5	2048	2048
29	2049	$37,989.7	$67,552.7	2049	2049
30	2050	$38,146.5	$67,969.9	2050	2050

*MY vehicles with negative net benefits

Table XI-19
Net-Benefit Analysis for **$13.3 Million VSLs**
(**@7 Percent** Discount, 2014 $ in Millions)

Year	Model Year	Net Benefits		MY With Positive Net Befits	
		Low	High	Low	High
1	2021	-$2,885.8	-$2,213.7	*	*
2	2022	-$3,914.5	-$2,386.0	*	*
3	2023	-$4,702.2	-$1,825.7	*	*
4	2024	-$3,775.4	$1,993.1	*	2024
5	2025	-$1,815.6	$6,461.6	*	2025

6	2026	$2,010.9	$14,208.9	2026	2026
7	2027	$7,960.8	$22,947.3	2027	2027
8	2028	$13,466.5	$27,843.4	2028	2028
9	2029	$17,252.3	$29,648.6	2029	2029
10	2030	$20,624.8	$31,450.2	2030	2030
11	2031	$22,855.9	$34,078.5	2031	2031
12	2032	$23,938.7	$37,672.7	2032	2032
13	2033	$24,918.4	$40,883.0	2033	2033
14	2034	$25,876.5	$43,855.2	2034	2034
15	2035	$26,691.4	$46,440.7	2035	2035
16	2036	$27,453.8	$48,737.9	2036	2036
17	2037	$28,139.6	$50,767.7	2037	2037
18	2038	$28,652.8	$52,416.9	2038	2038
19	2039	$29,013.3	$53,890.6	2039	2039
20	2040	$29,515.8	$55,267.4	2040	2040
21	2041	$30,037.5	$56,742.6	2041	2041
22	2042	$29,181.2	$55,510.0	2042	2042
23	2043	$29,372.4	$56,088.5	2043	2043
24	2044	$29,546.3	$56,578.1	2044	2044
25	2045	$29,698.8	$57,024.1	2045	2045
26	2046	$29,869.4	$57,464.4	2046	2046
27	2047	$30,050.9	$57,910.9	2047	2047
28	2048	$30,181.7	$58,290.8	2048	2048
29	2049	$30,334.4	$58,649.0	2049	2049
30	2050	$30,439.0	$58,999.6	2050	2050

*MY vehicles with negative net benefits

C. Summary of the Impacts from Alternative VSLs

The DOT 2015 guidance on treatment of VSL specifies that the economic analyses need to calculate high and low alternative estimates of the economic values of fatalities and injuries by using alternative VSLs of $5.2 million and $13.0 million in 2013 dollars. The corresponding VSLs in 2014 dollars are $5.3 million and $13.2 million, respectively. Using the $5.3 million lower range VSL in the analysis results in a 34.6 percent reduction in estimated monetized benefits (annual and MY) compared to the primary estimates using $9.4 million VSL. For the lower range VSL, the proposed rule would reach the breakeven year between 2031 and 2035, about 2 to 3 years later than those estimated in the main analysis using $9.4 million VSL. In contrast, when the $13.2 million upper range VSL is used, the proposed rule would accrue 31.9 percent more monetized benefits. With the upper range VSL, the proposed rule would reach the breakeven year between 2029 and 2031, potentially one year earlier than the primary estimates.

Per MY vehicle based, the proposed rule would be cost-effective between MY 2024 and MY 2026 vehicles for both VSLs. The proposed rule also would accrue positive net benefits between these two MY vehicles for both VSLs. These MYs for high and low VSLs do not deviate from the MYs estimated in the main analysis.

In summary, taking into account the range of VSL from $5.3 to $13.2 million, the lower range of the monetized benefits would be 65.4 percent (0.654) of the primary estimates and the upper range of the monetized benefits would be 1.319 times the primary estimates. The VSL analysis shows that the high and low VSLs affect mostly the breakeven analysis. The breakeven years can be either one year early or three year later than the primary estimated years. However, the VSL range has almost no impact on the cost-effectiveness and net-benefit analyses. Table XI-20 summarizes the cost-benefit measures for the two alternative VSLs.

Table XI-20

Summary of Cost-Benefit Measures

Cost-Benefit Measures	$5.3 Million VSL		$13.2 Million VSL	
	3%	7%	3%	7%
Breakeven (CY)	2031 – 2034	2031 – 2035	2029 – 2030	2029 – 2031
Cost-Effectiveness (MY)	2024 – 2027	2025 – 2027	2024 – 2026	2024 – 2026
Positive Net Benefits (MY)	2025 – 2027	2025 – 2027	2024 – 2026	2024 – 2026

CY: calendar year, MY: model year of vehicles

CHAPTER XII. PROBABILISTIC UNCERTAINTY ANALYSIS

This chapter identifies and quantifies the major uncertainties in the breakeven, cost-effectiveness and net benefit (benefit-cost) analyses and examines the impacts of these uncertainties on the outcome from these analyses. Throughout the course of these analyses, many assumptions were made, diverse data sources were used, and different statistical processes were applied. The variability of these assumptions, data sources, and statistical processes potentially would influence the estimated regulatory outcomes. Thus, all these assumptions, data sources, and derived statistics can be considered as uncertainty factors for the regulatory analysis. The purpose of this uncertainty analysis is to identify the uncertainty factors with appreciable variability, quantify these uncertainty factors by appropriate probability distributions, and induce the probabilistic outcomes accompanied with degrees of probability or plausibility. This facilitates a more informed decision-making process.

A Monte Carlo statistical simulation technique[162] is used to accomplish the process. The technique is to first randomly select values for those uncertainty factors from their pre-established probability distributions. The selected values then are fed back to the breakeven, cost-effectiveness, and net benefit analyses to generate all possible outcomes. The process is run repeatedly. Each complete run is a trial. Crystal Ball®[163], a spreadsheet-based risk analysis and forecasting software package which includes the Monte Carlo simulation technique tool, was chosen to automate the process. In addition to simulation results, Crystal Ball® also provides the degree of certainty (or confidence, or credibility) that is associated with the simulated results. The degree of certainty provides the decision-makers an additional piece of important information to evaluate the outcomes.

The analysis starts by identifying significant uncertainty factors and quantifying their variability by a probability distribution. The next step is to simulate the model to obtain probabilistic

[162] See a: Robert, C.P. & Casella, G., *Monte Carlo Statistical Methods*, Springer-Verlag New York, Inc., 1999, and b: Liu, J.S., *Monte Carlo Strategies in Scientific Computing*, Springer-Verlag New York, Inc., 2001 (Or any statistics books describing the Monte Carlo simulation theory are good references for understanding the technique).

[163] A registered trademark of Decisioneering, Inc.

results rather than single-value estimates. The simulation repeats the trials until certain pre-defined criteria[164] are met and a probability distribution of results is generated.

A. Uncertainty Factors

In the breakeven, cost-effectiveness, and net benefit analyses, benefits and costs are the two primary components. As described in the Benefits chapter, benefits are a function of target population, effectiveness of apps, and communication rates. Communication rates also depend on new vehicles sold annually. Thus, target population, effectiveness of apps, and new vehicles sold are sources of uncertainty for benefits.

Costs comprised four parts as described in the cost chapter: vehicle technology, SCMS, communication (between vehicles and SCMS), and fuel economy impact. Vehicle technology cost is a function of the unit technology costs (i.e., vehicle components and apps) and the number of vehicles that would be equipped with the technology. SCMS is a function of many variables: labor cost, energy costs, computer equipment costs, HSM costs, PKI implementation costs (i.e., certificate distribution frequency and size), facility rent costs, facility construction costs, the number needed for each of the SCMS functions, and the number of vehicles that would have the V2V technology. Communication cost depends on the unit cost of RSE, number of RSE, unit cost for communication component, cost of electronic data transfer, data transfer size and frequency, communication network cost, misbehavior rate, the size of CRL. Fuel economy impact varies with the added weight, base fuel economy (i.e., miles per gallon- mpg), VMT (vehicle miles traveled), fuel price, and the number of affected vehicles. All these elements are sources of uncertainty for costs.

For benefits, we identified two significant uncertainty factors: target population, effectiveness of apps, and app adoption rates. Communication rate is a function of app adoption rates and vehicle sold, therefore, it is not considered as a significant factor by itself. Specifically, the

[164] The pre-defined criteria may change with each uncertainty analysis. In this case, we require a 99 percent precision in mean for each simulated outcome such as total costs, cost-effectiveness, and net benefits as described later.

communication rate for a particular year is, in simplified terms, the ratio of the square term of vehicles with apps to the square term of all on-road light vehicles. Thus, within a year variation of projected new vehicle production would affect slightly the annual communication rate. Therefore, communication rate is treated as constant. Furthermore, we did not adjust the safety target population for vehicle sales. Therefore, communication rate would not be a significant factor.

For costs, as described previously, there are too many sources of uncertainty. Therefore, it is not practical to determine the variability associated with all these sources. Since the majority of the costs (about 90%) come from vehicle technology costs, we believe that applying the variation of the technology costs to the "all other" cost categories (i.e., SCMS, communication, and fuel economy) would be sufficient to address the uncertainty surrounding the costs. By applying the same variation to all cost categories, in essence, we treated the costs as whole (i.e., one significant factor) in the analysis.

Significant Uncertainty Factors

The section discusses the four identified significant factors and their probability distributions.

Target population

Target population is important to benefit estimates because it defines the crash population of risk without the rule. The major uncertainties in this factor arise from sources such as demographic projections, driver/occupant behavioral changes (e.g., shifts in safety belt use), increased roadway travel, new Government safety regulations, and survey errors in NHTSA's data sampling system GES.

The impact of demographic and driver/occupant behavior changes, roadway traveling, and new automobile safety regulations are reflected in the FARS and GES crash databases. Thus, the analysis examined the historic FARS and GES to determine whether variations resulting from these uncertainty sources would warrant further adjustments to the future target crash population. Based on 1990 to 2013 FARS, the fatal crashes continue to fall to the lowest point in 2011 then slightly increase in 2012 and 2013. The average of 2010 to 2013 fatalities thus represents the lowest level fatalities. The lowest level would not be reduced without further introduction of new regulations and safety systems. Furthermore, the decrease and increase occurs even when the estimated VMT continue to increase during the same period. Since the fatalities are around the lowest and there is no definitive relationship between fatalities and VMT, we did not adjust fatalities further. GES data yield a similar result for non-fatal crashes and injuries. Therefore, we did not further adjust the target population to account for variations associated with these uncertainty sources. Accordingly, only survey errors from GES are considered here. For the analysis, we used the 90 percent confidence interval (i.e., 1.645 standard errors) of the survey errors (for GES) as the low and high bounds of non-fatal crashes (MAIS 1-5 injuries) and PDOVs. In other words, fatal crashes and fatalities were treated as constants. Non-fatal crashes (MAIS 1-5 injuries and PDOVs) have variations and were treated as uniformly distributed between the 90 percent confidence interval of the primary estimates (i.e., means).

The standard errors (SE) can be generated using the following formula:[165]

$$SE = e^{a+b(\ln x)^2}$$

Where, x = number of crashes a = 4.372800 b = 0.035270	Where x = number of injuries a = 4.314880 b = 0.035590	Where x = number of vehicles a = 4.395660 b = 0.036700

From the target population in the Benefit chapter, there are 1.06 million target crashes, 687,313 MAIS 1-5 injuries, and 1.29 million PDOVs. These are considered as the statistical means for these injury categories. Substituting x in the formula above with the number of crashes, injuries and vehicles derives one SE for crashes, injuries, and PDOVs, respectively. One SE was estimated to be 70,500, 46,400, and 116,300 for target crashes, injuries, and PDOVs, respectively. However, the uniform distributions for crashes, injures, and PDOVs cannot be established independently of each other since they are not independent (i.e., more crashes occurs, more injuries and PDOVs are expected). To address the inter-dependency issue, we established

[165] Table C.1, Traffic Safety Facts 2013, National Highway Traffic Safety Administration

a factor that would be simultaneously applied to crashes, injuries, and PDOVs. We observed that one SE is about 7 percent of the mean for crashes and injuries and 9 percent of the mean for PDOVs. Considering PDOVs comprised a relatively small portion of monetized benefits to injuries, we decided to use 7 percent of the mean estimates as one SE to address the survey errors for crashes, injuries, and PDOVs. Thus, target population would range from (1-1.645*0.07)*mean to (1+1.645*0.07)*mean (i.e., between 0.88*mean 1.12*mean). Essentially, for each simulation run, a factor within (0.88, 1.12) is randomly chosen and is applied to the mean to establish the target population for that specific run. The following depicts the uniform distribution of the target population.

As shown in the figures below, IMA and LTA crashes would range from 0.94 to 1.19 million, MAIS 1-5 injuries would range from 0.60 to 0.77 million, and PDOV would range from 1.14 to 1.45 million. Within the MAIS 1-5 injuries, the distribution of each MAIS injuries is equal to that of the primary distribution in the main analysis.

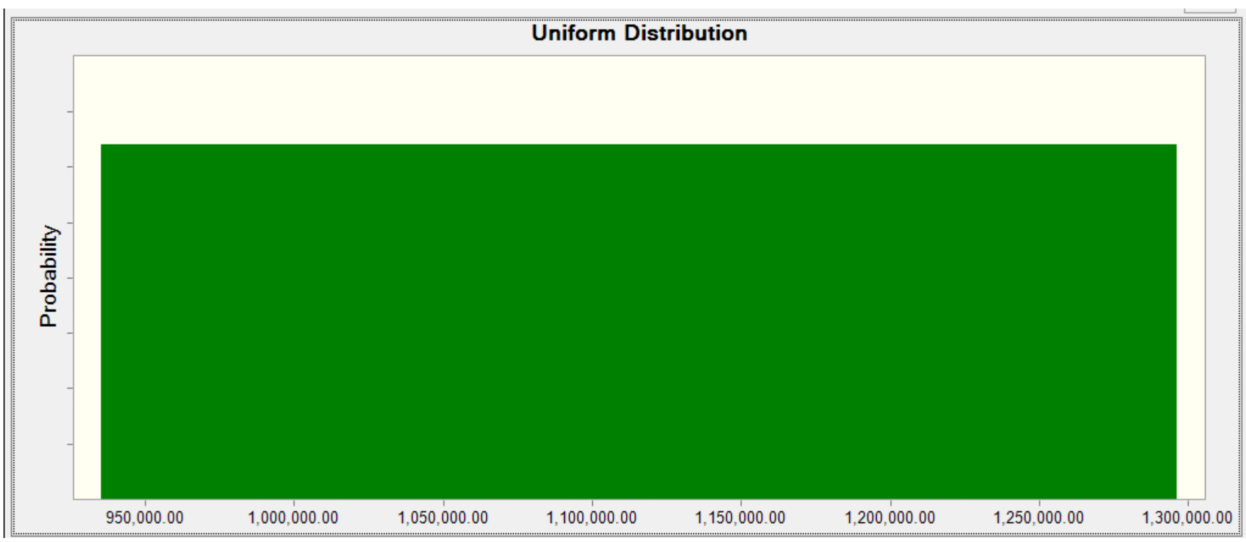


Figure XII-1
Uniform Distribution for IMA and LTA Crashes

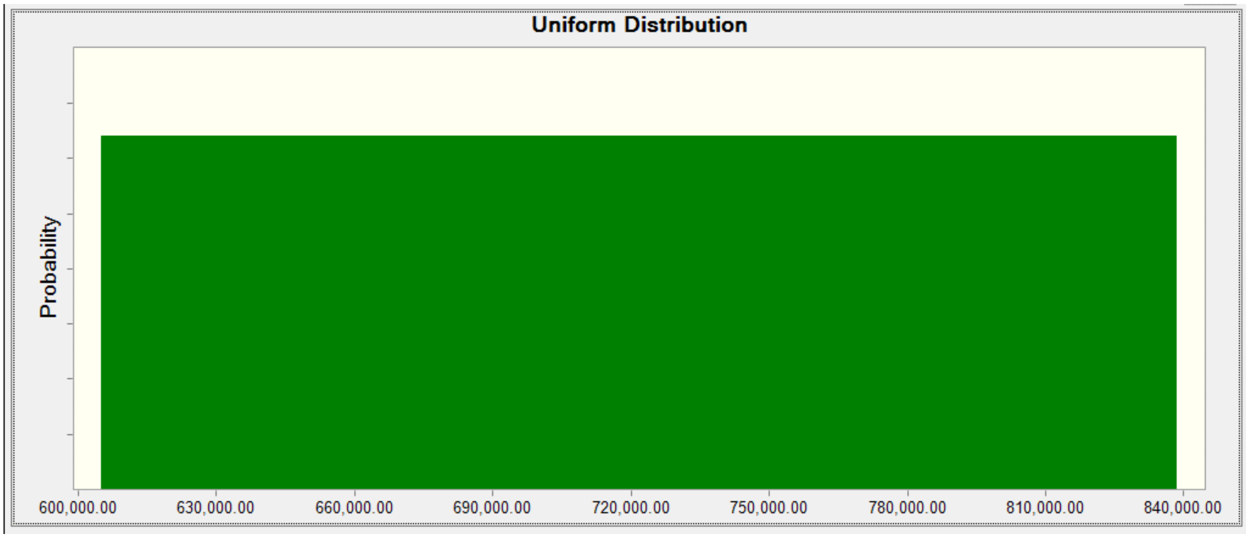


Figure XII-2
Uniform Distribution for IMA and LTA MAIS 1-5 Injuries

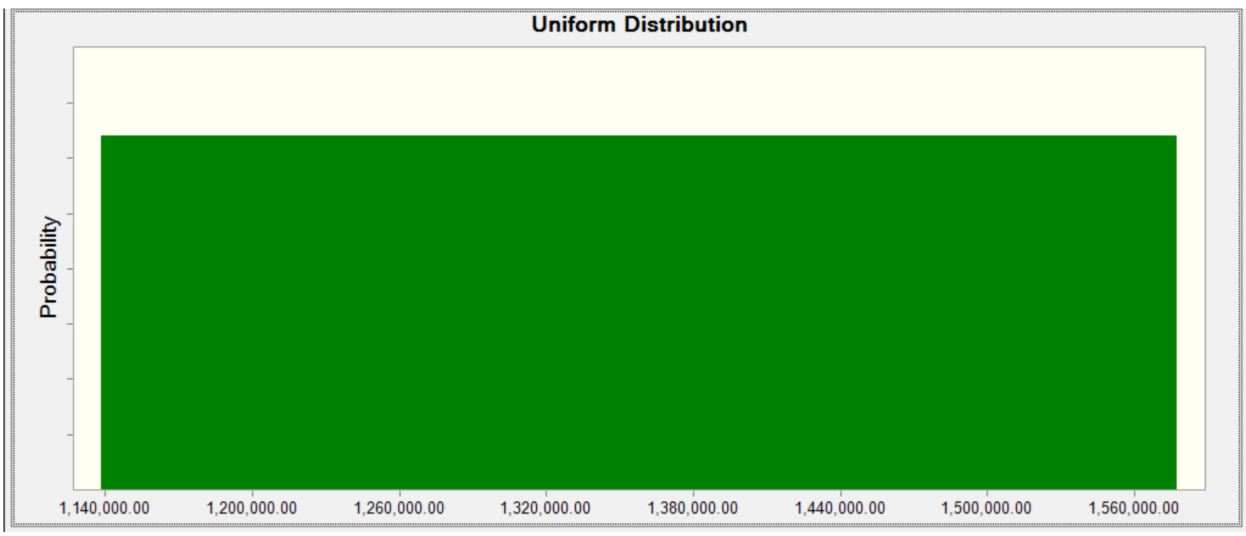
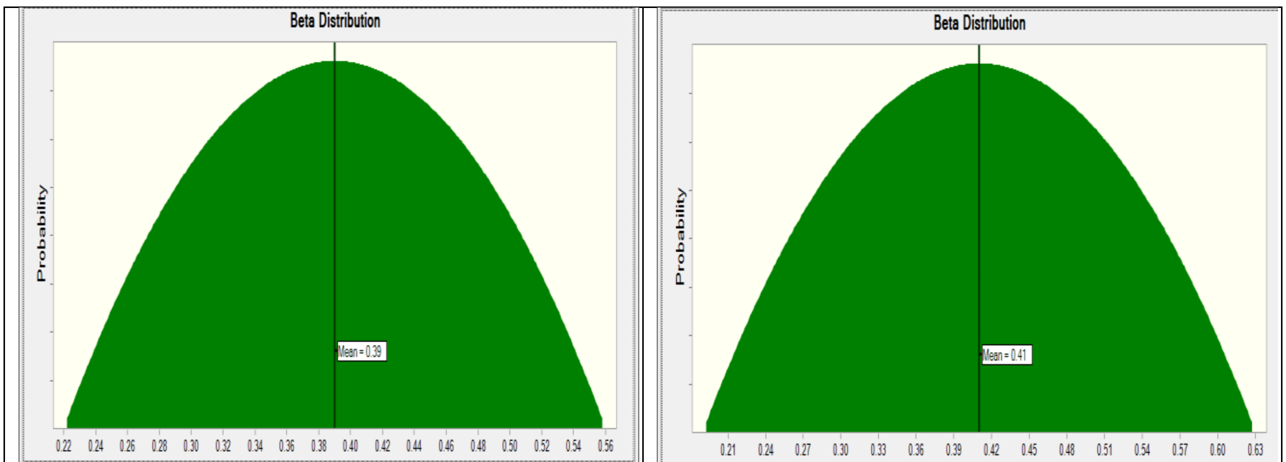


Figure XII-3
Uniform Distribution for IMA and LTA PDOVs

Effectiveness of apps (i.e., IMA and LTA)

IMA and LTA effectiveness rates are expected sources of uncertainty since they were derived based on computer simulations with limited crash scenarios, simplified vehicle dynamic response and vehicle conflict environment. Thus, the primary sources of uncertainty for the effectiveness rate include the simulation errors inherent in the SIM tools, variations of the input parameters for SIM, and the representativeness of crash scenarios in MiniSim. To account for the impacts of these sources, we took a conservative approach by assuming a wider range for effectiveness rates. We assumed that the high effectiveness rate is the upper bound of the range and that half of the low effectiveness rate is the lower bound of the range. Therefore, the effectiveness for IMA would range from 22 to 56 percent with the mean of 39 percent. The effectiveness for LTA would range from 19 to 63 percent with the mean of 41 percent. The effectiveness rates for both IMA and LTA are treated as beta distributions within the corresponding boundary. Beta distributions were selected because of the boundary imposed for the effectiveness rates and its flexibility. To establish a beta distribution, four parameters are required: minimum, maximum, alpha and beta. Minimum and maximum define the boundary of the effectiveness. The alpha and beta values determine the shape of the distribution curves. We also assumed that within the boundary, effectiveness is normally distributed around the mean. Therefore, alpha and beta have an equal value of 2. The following depicts the beta distribution for IMA and LTA.



IMA Effectiveness Range: 22 to 56% Mean: 39%	LTA Effectiveness Range: 19 to 63% Mean: 41%

Figure XII-4
Beta Distribution for Effectiveness of IMA and LTA

Safety App Adoption Rates

For safety apps, since the agency is not proposing to mandate any at this time, apps will be introduced based on a market-driven adoption rate. The agency used the NCAP data, industry comments, and a survey study to make the best judgement on the app adoption rate scenario for the proposed rule in the primary analysis (primary app curve). Without specific product plans from the industry, the actual adoption rates of V2V-enabled safety apps are expected to vary from the primary app adoption rates. Based on the relatively low costs of the app, the agency believes that the industry most likely will utilize V2V-enabled apps to improve safety, mobility, and environment. However, the agency recognizes that many other factors such as the utility, complexity, maturity, and customers' acceptance of an app all can influence the deployment of that app. Therefore, the app adoption comes with greater uncertainty. To address this issue, the analysis used the app adoption rates from the alternative that would mandate DSCR and apps as the upper bound of the app adoption. For the lower bound of adoption rate, the agency assumed a one year delay and 25 percent lower adoption rate. In other words, for the lower bound, the apps will be implemented starting 2023 with a rate 75 percent of the 2022 primary rate. At this rate, the implementation will not reach the 100 percent until 2030, two years later then the primary adoption rates. Furthermore, as discussed in the Regulatory Alternative chapter, it will be a tremendous challenge for the industry to meet the upper bound of app adoption. Therefore, the upper bound is least likely scenario to be selected in the simulation process. In addition, based on the principal of regression to the mean (i.e., the primary curve), the probability of selection of the lower bound curve also will be smaller than that of the primary curve. For these reasons, the agency assumes that the probability of selecting the upper bound, the primary, and the lower bound is 10 percent, 75 percent, and 15 percent, respectively. Table XII-1 lists these adoption rates. Figure XII-1 depicts the upper (Mandating Apps), primary (Free-Market Primary), and the lower (Free-Market Alternative) app adoption curves. The agency believes that the primary curve is feasible and reasonable, and that the wide variation between the lower and higher bound is sufficient to describe the uncertainty of the free-market variation. Comments are requested on the adoption rates used for this analysis.

Table XII-1

V2V Technology Adoption Scenarios for Uncertainty Analysis

Year (MY)	1 (2021)	2 (2022)	3 (2023)	4 (2024)	5 (2025)	6 (2026)	7 (2027)	8 (2028)	9 (2029)	10 (2030)
Upper	50%	75%	100%	100%	100%	100%	100%	100%	100%	100%
Primary	0%	5%	10%	25%	40%	65%	90%	100%	100%	100%
Lower	0%	0%	4%	8%	19%	30%	49%	68%	88%	100%

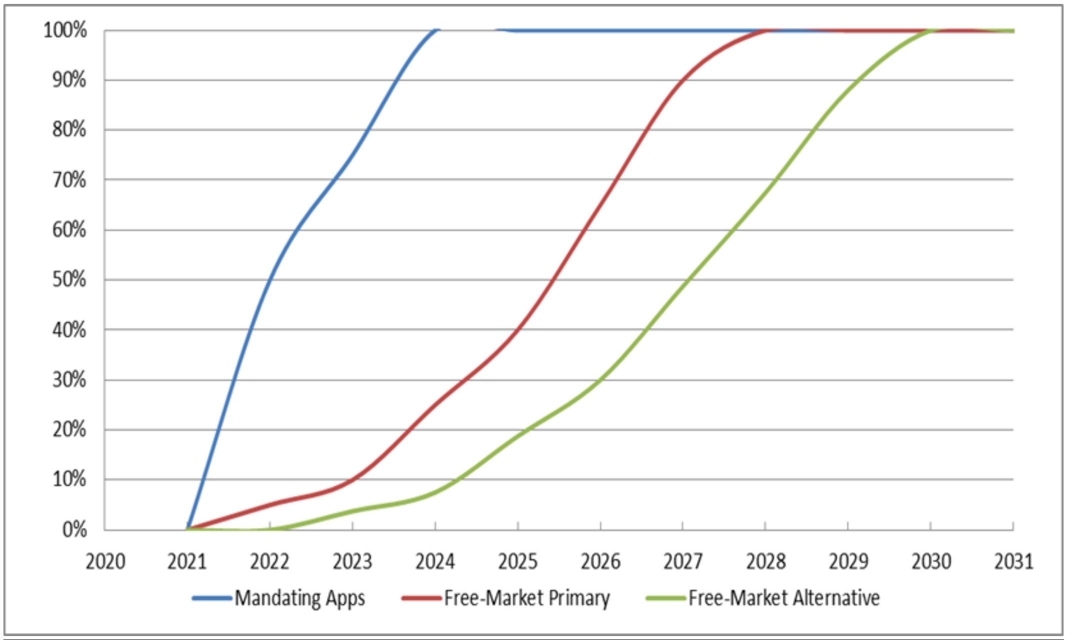


Figure XII-1
App Adoption scenarios

Costs

As discussed before, the majority the costs (about 90%) come from vehicle technology costs. Since the unit costs for technology components were based on suppliers' cost submissions, we believe that an overall 10 percent variation from the mean (i.e., annual costs, MY costs) would be sufficient to address the variations resulting from all the uncertainty sources for costs. The 10 percent variation is based on the agency's experience with the prior agency' cost estimates and tear-down studies. For a 10 percent variation, the total costs (i.e., for all four costs) vary in the range between 90% of the mean and 110% of the mean. The costs are treated as uniformly distributed. Establishing the uniform distribution indicates that any value in the range (90% of the mean, 110% of the mean) has an equal probability to be the true cost. Here, instead of proving 60 distributions for annual costs and another 30 for MY costs, we only provide a conceptual depiction of the uniform distribution for costs as shown in Figure XII-5. Establishing the uniform distribution, the annual costs and MY costs would range from $1.97 billion for 2021 to $5.48 billion for 2060. MY costs would range from $2.00 billion for the MY 2021 vehicles to $5.51 billion for MY 2050 vehicles. The difference between the annual and MY costs is fuel economy impact.

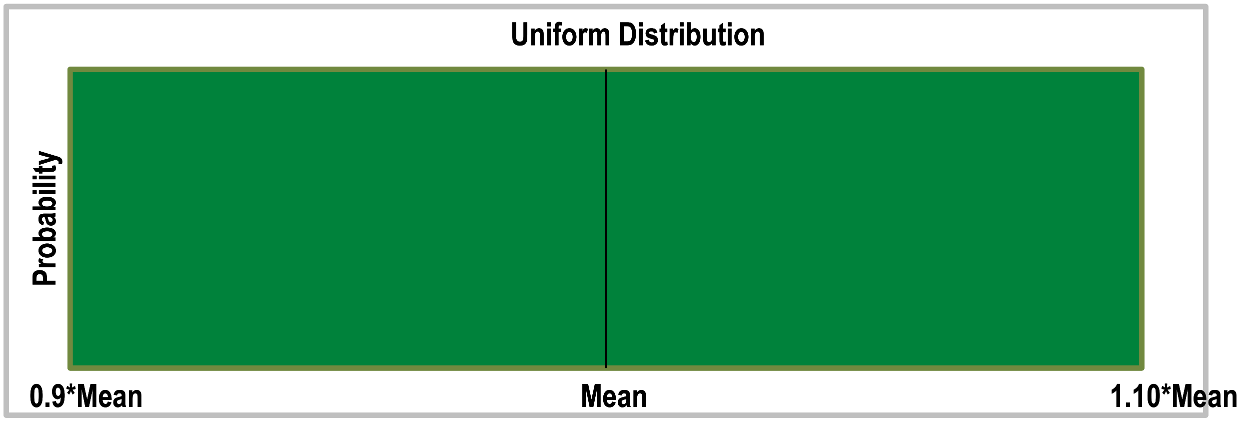


Figure XII-5
Conceptive Illustration of Uniform Distribution for Costs

B. Simulation Results

The Monte Carlo simulation first randomly selects a value for each of the significant factors based on their probability distributions as shown above. Then, the selected values are fed into the designated processes to forecast the results. The simulation repeats the process until a pre-defined accuracy has been accomplished. Since Crystal Ball is a spreadsheet-based simulation software, the simulation model actually is a step-wise process (i.e., the simulation estimates benefits, cost, fatal equivalents, breakeven, cost-effectiveness, and net benefits). Therefore, each of these forecasted results had certainty bounds. This uncertainty analysis conducted a total of 10,000 trials or the forecasted mean results reached 99 percent precision. These criteria were chosen to ensure the simulation errors ($\approx \frac{1}{10{,}000}$) would be insufficient and the results would truly reflect the probabilistic nature of the uncertainty factors.

Table XII-2 summarizes the breakeven simulation results. As shown, the proposed rule would reach the breakeven year between 2029 and 2034 at a 3 percent discount rate and 2029 to 2036 at a 7 percent discount rate. With the variability we established, the proposed rule would reach the breakeven year between 2030 and 2034 with 90 percent certainty.

Table XII-2
Summary of Breakeven Year

	3%	7%
Range	2027 – 2036	2027 – 2037
Most Likely Year	2030 – 2032	2031 – 2032
90% Certainty	2030 – 2033	2030 – 2034

Table XII-3 summarizes the simulation results for cost-effectiveness analysis. The earliest MY vehicles that would be cost-effective are between MY 2024 and MY 2027 vehicles for both discount rates with 90 percent certainty.

Table XII-3
Summary of MYs that Would Be Cost-Effective

	3%	7%
Range	2022 – 2028	2022 – 2028
Most Likely MY	2024 – 2026	2024 – 2026
90% Certainty	2024 – 2026	2024 – 2027

Table XII-4 summarizes net benefit analysis simulation results. Similar to cost effectiveness outcomes, the earliest MY vehicles that would accrue positive net benefits are between MY 2024 and MY 2027 for both discount rates with 90 percent certainty.

Table XII-4
Summary of MYs that Would Accrue Positive Net Benefits

	3%	7%
Range	2022 – 2028	2022 – 2029
Most Likely MY	2024 – 2026	2025 – 2027
90% Certainty	2024 – 2027	2024 – 2027

C. Summary

With the proposed rule, the agency is ushering in a new era of traffic safety. With this in mind, the analysis took a cautious approach for describing possible variability of the sources we used to estimate the benefits and costs. Specifically, the analysis used a wider range of more conservative app effectiveness rates to determine the impact of prescribed variability on the cost-benefit measures. Our analysis showed that the proposed rule would reach the breakeven year between 2030 and 3032 with 90 percent certainty. The most conservative scenario showed that the breakeven year would be five to six years later than the primarily estimated years. The cost-effectiveness and net benefits analyses resulting from the uncertainty analysis showed that the proposed rule would be cost-effective and would accrue positive net benefits between MY 2024 and MY 2027 with 90 percent certainty. This indicates that cost-effectiveness would be achieved at most one MY later than the primary estimated MYs. For the most conservative scenario, it would be two to three MYs later than the primarily estimated MYs.

CHAPTER XIII. REGULATORY FLEXIBILITY ACT AND UNFUNDED MANDATES REFORM ACT

A. Regulatory Flexibility Act

The Regulatory Flexibility Act of 1980 (5 U.S.C. §601 et seq.), as amended by the Small Business Regulatory Enforcement Fairness Act (SBREFA) of 1996, requires agencies to evaluate the potential effects of their proposed and final rules on small businesses, small organizations, and small governmental jurisdictions in the United States.

5 U.S.C. §603 requires agencies to prepare and make available for public comment an initial and a final regulatory flexibility analysis (RFA) describing the impact of proposed and final rules on small entities if the agency decides that the rule may have a significant economic impact on a substantial number of small entities. Each RFA must contain:

(1) A description of the reasons why action by the agency is being considered;

(2) A succinct statement of the objectives of, and legal basis for, a proposal or final rule;

(3) A description of and, where feasible, an estimate of the number of small entities to which the proposal or final rule will apply;

(4) A description of the projected reporting, record keeping and other compliance requirements of a proposal or final rule including an estimate of the classes of small entities which will be subject to the requirement and the type of professional skills necessary for preparation of the report or record;

(5) An identification, to the extent practicable, of all relevant Federal rules which may duplicate, overlap, or conflict with the proposal or final rule;

(6) Each final regulatory flexibility analysis shall also contain a description of any significant alternatives to the final rule which accomplish the stated objectives of applicable statutes and which minimize any significant economic impact of the final rule on small entities.

1. Description of the reasons why action by the agency is being considered

NHTSA is considering this action to require V2V technology in light vehicles in order to reduce the number of crashes and associated fatalities and injuries. Specifically, the proposed rule is examining the two V2V-based safety warning apps, IMA and LTA, in avoiding intersection and left turn crashes. Based on the agency's studies on the effectiveness of these two apps, IMA and LTA were found effective in reducing these two types of crashes which account for 19 percent of the total annual crashes and 31 percent of light vehicles-to-light vehicles crashes.

2. Objectives of, and legal basis for, the proposal or final rule

Under 49 U.S.C. 322(a), the Secretary of Transportation (the "Secretary") has authority to prescribe regulations to carry out the duties and powers of the Secretary. One of the duties of the Secretary is to administer the National Traffic and Motor Vehicle Safety Act, as amended (49 U.S.C. 30101 et seq.). The Secretary is authorized to issue Federal motor vehicle safety standards (FMVSS) that are practicable, meet the need for motor vehicle safety, and are stated in objective terms.[166] The Secretary has delegated the responsibility for carrying out the National Traffic and Motor Vehicle Safety Act to NHTSA.[167] NHTSA is adopting this rule under the Authority of 49 U.S.C. 322, 30111, 30115, 30117, and 30166; delegation of authority at 49 CFR 1.95.

3. Description and estimate of the number of small entities to which the proposal or final rule will apply

The proposed rule applies to vehicle manufacturers who produce light vehicles with a GVWR not greater than 11,793 kg (10,000 pounds) and second-stage or final-stage manufacturers and alterers.[168] The proposed rule will also impact manufacturers of DSRC radios, computer hardware devices manufacturers, encryption software and service companies, and communication device manufacturers. Business entities are defined as small businesses using

[166] 49 U.S.C. 30111(a).

[167] 49 U.S.C. 105 and 322; delegation of authority at 49 CFR 1.

[168] These manufacturers purchase incomplete vehicles from other large manufacturers and complete the manufacturing process.

the North American Industry Classification System (NAICS 2012) code[169], for the purposes of receiving Small Business Administration assistance. One of the criteria for determining size, as stated in 13 CFR 121.201[170], is the number of employees in the firm. The proposed rule would affect business in computer and electronic product manufacturers and transportation equipment manufacturing. Affected business in computer and electronic product manufacturers include: (a) To qualify as a small business in Radio and Television Broadcasting and Wireless Communications Equipment Manufacturing (NAICS 334220), the firm must have fewer than 750 employees, (b) Other Communications Equipment Manufacturing (NAICS 334290), the firm must have fewer than 750 employees, (c) Semiconductor and Related Device Manufacturing (NAICS 334416), the firm must have fewer than 500 employees, and (d) Software and Other Prerecorded Compact Disc, Tape, and Record Reproducing (NAICS 334614), the firm must have fewer than 750 employees.

Affected business in transportation equipment manufacturing include: (e) To qualify as a small business in Automotive Manufacturing (NAICS 336111), the firm must have fewer than 1000 employees, (f) In Light Truck and Utility Vehicle Manufacturing (NAICS 336112), the firm must have fewer than 1000 employees, (g) In Motor Vehicle Body Manufacturing (NAICS 336211), the firm must have fewer than 1000 employees, and (h) In All Other Motor Vehicle Parts Manufacturing (NAICS 336399), the firm must have fewer than 750 employees.

Small computer and electronic product manufacturers

The proposed rule would have positive economic effects on these types of manufacturers since they can make more money by selling V2V related security hardware, software, radio equipment, etc. to car manufacturers and consumers.

Small volume light vehicle manufacturers

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[169] The latest version modified by the Office of Management and Budget in 2012; https://www.census.gov/cgi-bin/sssd/naics/naicsrch?chart_code=31&search=2012 NAICS Search

[170] Effectiveness as of July 2014; http://www.sba.gov/content/small-business-size-standards

If adopted, the proposal would directly affect twenty single stage motor vehicle manufacturers.[171] None of these are qualified as small business. However, there are three U.S. domestic vehicle manufacturers that would qualify as a small business under the definitions of (e), (f), (g), and (h) above. Table XIII-1 provides information about the 4 small domestic manufacturers in MY 2005.

Table XIII-1
Small Vehicle Manufacturers

Manufacturer	Employees	Estimated Sales	Sale Price Range	Est. Revenues
Panoz[(1)]	70	25	$60,000 to $750,000	$*
Saleen	22	100	$40,000 to $150,000	$ 3,800,390**
Shelby[(2)]	44	60	$24,000 to $300,000	$2,110,000***

(1) A subsidiary of Delta Wing LLC
(2) A subsidiary of Carroll Shelby International, Inc.

*no information
** for the year ended March 2015[172]
*** projected from the nine months revenue ended September 30, 2003

The V2V technology would cost $249 to $351 per vehicle in the first year and costs would be gradually reduced afterwards due to the learning curve impact. Consumer costs for the more exotic models may be much higher than this. Compared to the least expensive vehicle in Table XIII-1, the cost could range from 1.0 percent ($249/$24,000 = 0.010) to 1.5 percent ($351/24,000 = 0.015). Compared to a weighted average sales price ($159,000), the cost could range 0.16 percent ($249/$159,000 = 0.0016) to 0.22 percent ($351/$159,000 = 0.0022). In the second year, for example, the share of V2V costs is expected to be 10 percent lower than that estimated percentage for the first year.

We believe that the market for the products of these small manufacturers is highly inelastic. Purchasers of these products are enticed by the desire to have an unusual vehicle. Furthermore, the price of competitor's models will also need to be raised by a similar amount, since all light

[171] BMW, Fiat/Chrysler (Ferrari and Maserati), Ford, Geely (Volvo), General Motors, Honda (Acura), Hyundai, Kia, Lotus, Mazda, Mercedes, Mitsubishi, Nissan (Infiniti), Porsche, Subaru, Suzuki, Tata (Jaguar and Land Rover), Tesla, Toyota (Lexus), and Volkswagen/Audi.

[172] http://compliance-sec.com/secfilings/company/slnn/link_files/2015/07-14-2015/Form10-K/Form10-K.pdf

vehicles must pass the standards. Thus, we do not believe that raising the price to include the value of V2V will have much, if any, effect on sales of these vehicles. We expect that these price increases will be passed on to customers. Based on this analysis, the agency believes that the proposed rule will not have a significant economic impact on these three small domestic vehicle manufacturers.

4. Description of the projected reporting, record keeping and other compliance requirements for small entities

The proposed rule requires manufacturers to equip their vehicles with V2V communication technology and to certify that their products comply with the standard. During the phase-in period, there is a requirement that manufacturers must provide information to NHTSA of the percent of their light vehicles that are certified to meet the standard, which is a record keeping requirement of the proposed rule.

5. Duplication with other Federal rules

There are no relevant Federal regulations that duplicate, overlap, or conflict with the proposed rule.

6. Description of any significant alternatives to the proposed rule

The agency considered an alternative that requires both the V2V technology and V2V-based safety applications. The agency decided not to adopt the alternative since the agency believes that additional research is needed. Specifically, the research for establishing test procedures and performance of the apps is critical to an effective app in reducing crashes and meeting the requirements of the Motor Vehicle Safety Act.

The agency believes the proposed rule mandating only the V2V communication technology allows for the implementation of interoperable V2V communication devices. This removes the biggest obstacle from the deployment of V2V-based apps. Thus, this will encourage a free-market approach for the development and deployment of safety applications, which the agency believes will be innovated.

B. Unfunded Mandates Reform Act

The Unfunded Mandates Reform Act of 1995 (Public Law 104-4) requires agencies to prepare a written assessment of the costs, benefits, and other effects of proposed or final rules that include a Federal mandate likely to result in the expenditures by State, local or tribal governments, in the aggregate, or by the private sector, of more than $100 million annually (adjusted annually for inflation with base year of 1995). Adjusting this amount by the implicit gross domestic product price deflator for the year 2014 results in $144 million (108.318/75.406 = 1.436). The assessment may be included in conjunction with other assessments, as it is here.

This proposed rule might result in expenditure by State, local or tribal governments but not more than $144 million annually. The proposed would result in an expenditure of much more than that magnitude by the automobile manufacturers. The estimated annual cost would range from $2.0 to $5 billion. These effects on automobile manufacturers have been discussed previously in the cost chapter.

C. Protection of Children from Environmental Health and Safety Risks

Executive Order 13045, “Protection of Children from Environmental Health and Safety Risks” (62 FR 19855, April 23, 1997), applies to any rule that: (1) is determined to be “economically significant” as defined under Executive Order 12866, and (2) concerns an environmental, health, or safety risk that the agency has reason to believe may have a disproportionate effect on children. If the regulatory action meets both criteria, the agency must evaluate the environmental health or safety effects of the planned rule on children, and explain why the planned regulation is preferable to other potentially effective and reasonably feasible alternatives considered by the agency.

This notice is part of a rulemaking that is not expected to have a disproportionate health or safety impact on children. Consequently, no further analysis is required under Executive Order 13045.

D. National Environmental Policy Act

NHTSA has analyzed this rulemaking action for the purposes of the National Environmental Policy Act. The agency has determined that implementation of this proposed action will not have any significant impact on the quality of the human environment.

APPENDIX A. SUPPORTING DATA

This Appendix provides historical vehicle sales data, base VMT, and survival probability that were used to derive projected vehicle sales, projected VMT, communication rates among vehicles, and discount factors – the critical elements for benefit and cost estimates. In addition, the Appendix also provides detailed comprehensive cost components and its unit costs for VSL of $9.4, $5.3, and $13.2 million. The comprehensive costs for $9.4 million VSL were used to derive the primary monetized benefits (i.e., the benefits of the proposed rule) and the other two alternative VSLs were used in the sensitive analysis to assess variations of monetized benefits.

A. Vehicle Sales and Projections

Table A-1 shows the historical vehicle sales that were used to project the future vehicle sales volumes. Initially, the 1994 to 2012 data were fitted into a regression model in the ANPRM to make the projection. Recent validation of the projected sale volume indicated that the regression models overestimated the 2013 sales significantly. Therefore, for the PRIA, the agency has adjusted the vehicle sales projected for the ANPRM further by applying an adjustment factor to the initially projected vehicle sales volume. The factor is the ratio of the 2013 sales published in the Ward's 2014 Automotive Yearbook to the 2013 sales established in the ANPRM. The adjustment factor is 0.89 for PCs and 1.02 for LTVs. Applying these adjustment factors results in the revised projected PC sales 11 percent lower than the previously predicted level and LTVs 2 percent higher. Table A-2 shows the revised projected vehicle sales from 2021 to 2050. Sale volumes after 2050 are assumed to remain constant at the 2050 level.

Table A-1
Historical Vehicle Sales from1994 to 2013
(Million)

Year	Cars	Light Trucks/Vans	Total	Year	Cars	Light Trucks/Vans	Total
1974	8.85	2.44	11.30	1996	8.48	6.62	15.10
1975	8.61	2.28	10.90	1997	8.22	6.90	15.12
1976	10.10	2.96	13.05	1998	8.08	7.46	15.54
1977	11.17	3.43	14.60	1999	8.64	8.26	16.89
1978	11.30	3.81	15.11	2000	8.78	8.57	17.35

1979	10.65	3.32	13.96	2001	8.35	8.77	17.12
1980	8.97	2.44	11.41	2002	8.04	8.77	16.82
1981	8.53	2.19	10.72	2003	7.56	9.08	16.64
1982	7.98	2.44	10.42	2004	7.48	9.38	16.87
1983	9.18	2.92	12.10	2005	7.66	9.29	16.95
1984	10.39	3.98	14.37	2006	7.76	8.74	16.50
1985	11.04	4.64	15.68	2007	7.56	8.53	16.09
1986	11.46	4.90	16.36	2008	6.77	6.43	13.19
1987	10.28	4.95	15.22	2009	5.40	5.00	10.40
1988	10.54	4.92	15.46	2010	5.64	5.92	11.55
1989	9.78	4.76	14.54	2011	6.09	6.65	12.74
1990	9.30	4.57	13.87	2012	7.24	7.20	14.44
1991	8.18	4.14	12.33	2013	7.59	7.69	15.28
1992	8.21	4.66	12.87				
1993	8.52	5.38	13.90				
1994	8.99	6.07	15.06				
1995	8.62	6.11	14.73				

Source: Wards' Automotive Yearbook

Table A-2

Projected Vehicle Sales from 2014 to 2050*

(Million)

Year	Cars	Light Trucks/Vans	Total	Year	Cars	Light Trucks/Vans	Total
2014	7.92	7.88	15.80	2037	9.35	8.99	18.34
2015	8.13	8.07	16.20	2038	9.43	9.06	18.49
2016	8.14	8.26	16.40	2039	9.51	9.15	18.66
2017	8.07	8.09	16.16	2040	9.62	9.25	18.87
2018	8.04	7.88	15.92	2041	9.76	9.38	19.14
2019	8.24	7.79	16.03	2042	9.18	9.38	18.56
2020	8.24	7.94	16.18	2043	9.23	9.43	18.66
2021	8.25	7.94	16.19	2044	9.27	9.49	18.76
2022	8.33	8.01	16.34	2045	9.32	9.55	18.87
2023	8.38	8.06	16.44	2046	9.37	9.60	18.97
2024	8.43	8.10	16.53	2047	9.42	9.66	19.08
2025	8.50	8.17	16.67	2048	9.46	9.72	19.18
2026	8.54	8.21	16.75	2049	9.51	9.77	19.28
2027	8.61	8.27	16.88	2050	9.56	9.83	19.39
2028	8.69	8.34	17.03				
2029	8.74	8.39	17.13				
2030	8.82	8.48	17.30				
2031	8.89	8.55	17.44				

2032	8.95	8.61	17.56				
2033	9.01	8.66	17.67				
2034	9.10	8.74	17.84				
2035	9.18	8.82	18.00				

* Sales volumes for 2051 and later model years are assumed to remain at the 2050 level

B. VMT Projections

Table A-3 presents the average VMT by vehicle age for 2008 and the projected VMT for 2021. The 2008 VMT was derived based on the methodology that was described in the agency report on vehicle survivability and travel mileage schedules.[173] The projection was based on the increase percentage reported in the AEO 2014. The report concluded that VMT per driver peaked at 12,900 miles in 2007 and decreased to 12,500 miles in 2012.[174] This implies a total of 3.1 percent decrease over the five year period. This is equivalent to a 0.63 percent (= $1 - \sqrt[5]{\frac{125000}{129000}}$) annual decrease between 2007 and 2012. In addition, the report suggested two possible VMT growth patterns for a sensitivity study. The lower VMT growth pattern assumed a 0.5% annual decrease and the high VMT growth pattern assumed the annual VMT increased by the following percentages: 0.3 percent for 2013, 0.4 percent for 2016, 0.5 percent for 2019, 0.6 percent for 2023, 0.5 percent for 2027, 0.4 percent for 2032, and 0.3 percent for 2036-2040. VMT primarily affects fuel economy impacts. To be conservative, the PRIA used the high growth pattern to adjust the 2008 VMT to future years. Therefore, VMT decreased annually by 0.63 percent from 2008 to 2012 and then increased from 2013 to 2040 according to the rates indicated by the high growth pattern. For years with a specified increase rate, their increase rates

[173] Lu, S., "Vehicle Survivability and Travel Mileage Schedules", NHTSA Technical Report, January 2006, DOT 809 952

[174] Page IF-22, Annual Energy Outlook, with Projections to 2040, U.S. Energy Information Administration, Department of Energy, DOE/EIA 0383 (2014) April 2014

are assumed to be the level of the closest early year. For example, the increase for 2015 is assumed to be at the 2013 level of 0.3 percent.

Table A-3
2008 and 2021 VMT
(Miles)

Age of the Vehicle	2008 VMT		Projected 2021 VMT	
	Cars	Light Trucks/Vans	Cars	Light Trucks/Vans
1	14700	15974	14857	16145
2	14252	15404	14405	15569
3	14025	14841	14175	15000
4	13593	14435	13738	14589
5	13324	14038	13467	14187
6	13064	13650	13203	13797
7	12809	12590	12946	12726
8	11378	12192	11499	12324
9	11087	11810	11206	11937
10	10806	11443	10923	11565
11	10535	11091	10648	11210
12	10273	10755	10382	10871
13	10021	10434	10127	10546
14	9779	10129	9885	10238
15	9547	9839	9651	9944
16	9324	9564	9423	9668
17	9111	9305	9210	9404
18	8908	9061	9003	9160
19	8714	8833	8807	8928
20	8530	8620	8622	8711
21	8356	8423	8446	8513
22	8192	8241	8278	8328
23	8037	8075	8124	8162
24	7892	7923	7975	8007
25	7757	7788	7842	7873
26	7632	7668	7712	7748
27	7516	7563	7598	7644
28	7410	7473	7489	7554
29	7314	7399	7393	7479
30	7227	7341	7303	7421
31		7298		7376
32		7270		7347
33		7258		7335
34		7246		7323
35		7233		7310
36		7221		7298
37		7209		7285

C. Survival Probability and Raw Discount Factors

Table A-3 shows the vehicle survival probability and raw discount factors for both 3 percent and 7 percent discount rates. The survival probabilities were derived using 1997-2010 R.L. Polk and National Vehicle Population Profile (NVPP). The survivability data differ between passenger cars and light trucks. The methodology of deriving these data was documented in the agency report on vehicle survivability and travel mileage schedules.[175] The raw discount factors used in the PRIA are the mid-year discount factors which acknowledge the fact that sales occur throughout the year.

[175] Lu, S., “Vehicle Survivability and Travel Mileage Schedules”, NHTSA Technical Report, January 2006, DOT 809 952

Table A-4
Survival Probability and Raw Discount Factors

Age of the Vehicle	Survival Probability		Raw Discount Factors*	
	Cars	Light Trucks/Vans	3%	7%
1	1.00000	1.00000	0.9853	0.9667
2	0.98784	0.97760	0.9566	0.9035
3	0.97659	0.96297	0.9288	0.8444
4	0.96144	0.94276	0.9017	0.7891
5	0.94505	0.93106	0.8755	0.7375
6	0.92983	0.91519	0.8500	0.6893
7	0.91130	0.89326	0.8252	0.6442
8	0.89119	0.87002	0.8012	0.6020
9	0.86888	0.84106	0.7778	0.5626
10	0.83971	0.79626	0.7552	0.5258
11	0.79989	0.74227	0.7332	0.4914
12	0.75563	0.69156	0.7118	0.4593
13	0.70551	0.64095	0.6911	0.4292
14	0.65266	0.58334	0.6710	0.4012
15	0.59458	0.53499	0.6514	0.3749
16	0.53107	0.48613	0.6324	0.3504
17	0.45848	0.44220	0.6140	0.3275
18	0.38319	0.39760	0.5961	0.3060
19	0.30772	0.35197	0.5788	0.2860
20	0.24140	0.30919	0.5619	0.2673
21	0.18328	0.26664	0.5456	0.2498
22	0.13878	0.22780	0.5297	0.2335
23	0.10657	0.20190	0.5142	0.2182
24	0.08203	0.17500	0.4993	0.2039
25	0.06294	0.15838	0.4847	0.1906
26	0.05142	0.14520	0.4706	0.1781
27	0.04195	0.13904	0.4569	0.1665
28	0.03369	0.12500	0.4436	0.1556
29	0.02815	0.11116	0.4307	0.1454
30	0.02352	0.10277	0.4181	0.1359
31	0.00000	0.09327	0.4059	0.1270
32	0.00000	0.08347	0.3941	0.1187
33	0.00000	0.07305	0.3826	0.1109
34	0.00000	0.06191	0.3715	0.1037
35	0.00000	0.05019	0.3607	0.0969
36	0.00000	0.03839	0.3502	0.0905
37	0.00000	0.02727	0.3400	0.0846

$$* \frac{1}{(1 + \text{discount rate})^{\text{age}-0.5}}$$

D. Exposure-Weighted Discount Factors

The exposure-weighted discount factors generally were used to discount the lifetime benefits to reflect their present values. Survival probability, raw discount factors, and VMT were used to derive these factors. VMT in this process serves as the exposure data. Tables A-5 and A-6 illustrate the process of deriving exposure-weighted discount factors at a 3 percent discount rate for PCs and LTVs, respectively. Tables A-7 and A-8 show the same process for the 7 percent discount rate. As indicated in these tables, the discounting process results in a factor of 0.8023 for PCs and 0.7864 for LTVs at a 3 percent discounted rate. For the 7 percent discounted rate, these factors are 0.6266 and 0.6076 for PCs and LTVs, respectively. These figures represent the portion of their present value. For example, the present value of the benefits for PCs at a 3 percent discounted rate is equivalent to 0.8023 of the initial estimates. Thus, if the initial monetized benefit were $100, the discounted benefit would be $80.23.

Table A-5
Exposure-weighted Discount Rate for **PCs**
(**3%** Discount Rate, lifespan 30 years)

Age	Survival Probability	Exposure (VMT)	Weighted Exposure (VMT) (a)	Weighted Exposure Proportion (b)	Discount Factor Raw (c)	Discount Factor Exposure-Weighted (d)
1	1.00000	14857	14,857	0.0819	0.9853	0.0807
2	0.98784	14405	14,230	0.0785	0.9566	0.0751
3	0.97659	14175	13,843	0.0763	0.9288	0.0709
4	0.96144	13738	13,208	0.0728	0.9017	0.0656
5	0.94505	13467	12,727	0.0702	0.8755	0.0615
6	0.92983	13203	12,277	0.0677	0.8500	0.0575
7	0.91130	12946	11,798	0.0651	0.8252	0.0537
8	0.89119	11499	10,248	0.0565	0.8012	0.0453
9	0.86888	11206	9,737	0.0537	0.7778	0.0418
10	0.83971	10923	9,172	0.0506	0.7552	0.0382
11	0.79989	10648	8,517	0.0470	0.7332	0.0345
12	0.75563	10382	7,845	0.0433	0.7118	0.0308
13	0.70551	10127	7,145	0.0394	0.6911	0.0272
14	0.65266	9885	6,452	0.0356	0.6710	0.0239
15	0.59458	9651	5,738	0.0316	0.6514	0.0206
16	0.53107	9423	5,004	0.0276	0.6324	0.0175
17	0.45848	9210	4,223	0.0233	0.6140	0.0143
18	0.38319	9003	3,450	0.0190	0.5961	0.0113
19	0.30772	8807	2,710	0.0149	0.5788	0.0086
20	0.24140	8622	2,081	0.0115	0.5619	0.0065
21	0.18328	8446	1,548	0.0085	0.5456	0.0046
22	0.13878	8278	1,149	0.0063	0.5297	0.0033
23	0.10657	8124	866	0.0048	0.5142	0.0025
24	0.08203	7975	654	0.0036	0.4993	0.0018
25	0.06294	7842	494	0.0027	0.4847	0.0013
26	0.05142	7712	397	0.0022	0.4706	0.0010
27	0.04195	7598	319	0.0018	0.4569	0.0008
28	0.03369	7489	252	0.0014	0.4436	0.0006
29	0.02815	7393	208	0.0011	0.4307	0.0005
30	0.02352	7303	172	0.0009	0.4181	0.0004
					Total	0.8023

a = Survival Probability * Exposure; $b = \frac{b}{\sum a}$; $c = \frac{1}{(1+3\%)^{age-0.5}}$; d = b*c

Table A-6
Exposure-weighted Discount Rate for **LTVs**
(**3%** Discount Rate, Lifespan 37 Years)

Age	Survival Probability	Exposure (VMT)	Weighted Exposure (VMT) (a)	Weighted Exposure Proportion (b)	Discount Factor Raw (c)	Discount Factor Exposure-Weighted (d)
1	1.00000	16145	16,145	0.0827	0.9853	0.0815
2	0.97760	15569	15,220	0.0779	0.9566	0.0745
3	0.96297	15000	14,445	0.0740	0.9288	0.0687
4	0.94276	14589	13,754	0.0704	0.9017	0.0635
5	0.93106	14187	13,209	0.0676	0.8755	0.0592
6	0.91519	13797	12,627	0.0647	0.8500	0.0550
7	0.89326	12726	11,368	0.0582	0.8252	0.0480
8	0.87002	12324	10,722	0.0549	0.8012	0.0440
9	0.84106	11937	10,040	0.0514	0.7778	0.0400
10	0.79626	11565	9,209	0.0472	0.7552	0.0356
11	0.74227	11210	8,321	0.0426	0.7332	0.0312
12	0.69156	10871	7,518	0.0385	0.7118	0.0274
13	0.64095	10546	6,759	0.0346	0.6911	0.0239
14	0.58334	10238	5,972	0.0306	0.6710	0.0205
15	0.53499	9944	5,320	0.0272	0.6514	0.0177
16	0.48613	9668	4,700	0.0241	0.6324	0.0152
17	0.44220	9404	4,158	0.0213	0.6140	0.0131
18	0.39760	9160	3,642	0.0186	0.5961	0.0111
19	0.35197	8928	3,142	0.0161	0.5788	0.0093
20	0.30919	8711	2,693	0.0138	0.5619	0.0078
21	0.26664	8513	2,270	0.0116	0.5456	0.0063
22	0.22780	8328	1,897	0.0097	0.5297	0.0051
23	0.20190	8162	1,648	0.0084	0.5142	0.0043
24	0.17500	8007	1,401	0.0072	0.4993	0.0036
25	0.15838	7873	1,247	0.0064	0.4847	0.0031
26	0.14520	7748	1,125	0.0058	0.4706	0.0027
27	0.13904	7644	1,063	0.0054	0.4569	0.0025
28	0.12500	7554	944	0.0048	0.4436	0.0021
29	0.11116	7479	831	0.0043	0.4307	0.0019
30	0.10277	7421	763	0.0039	0.4181	0.0016
31	0.09327	7376	688	0.0035	0.4059	0.0014
32	0.08347	7347	613	0.0031	0.3941	0.0012
33	0.07305	7335	536	0.0027	0.3826	0.0010
34	0.06191	7323	453	0.0023	0.3715	0.0009
35	0.05019	7310	367	0.0019	0.3607	0.0007

36	0.03839	7298	280	0.0014	0.3502	0.0005
37	0.02727	7285	199	0.0010	0.3400	0.0003
					Total	0.7864

a = Survival Probability * Exposure; b = $\frac{b}{\sum a}$; c = $\frac{1}{(1+3\%)^{age-0.5}}$; d = b*c

Table A-7
Exposure-weighted Discount Rate for **PCs**
(**7%** Discount Rate, lifespan 30 years)

Age	Survival Probability	Exposure (VMT)	Weighted Exposure (VMT) (a)	Weighted Exposure Proportion (b)	Discount Factor Raw (c)	Discount Factor Exposure-Weighted (d)
1	1.00000	14857	14,857	0.0819	0.9667	0.0792
2	0.98784	14405	14,230	0.0785	0.9035	0.0709
3	0.97659	14175	13,843	0.0763	0.8444	0.0644
4	0.96144	13738	13,208	0.0728	0.7891	0.0574
5	0.94505	13467	12,727	0.0702	0.7375	0.0518
6	0.92983	13203	12,277	0.0677	0.6893	0.0467
7	0.91130	12946	11,798	0.0651	0.6442	0.0419
8	0.89119	11499	10,248	0.0565	0.6020	0.0340
9	0.86888	11206	9,737	0.0537	0.5626	0.0302
10	0.83971	10923	9,172	0.0506	0.5258	0.0266
11	0.79989	10648	8,517	0.0470	0.4914	0.0231
12	0.75563	10382	7,845	0.0433	0.4593	0.0199
13	0.70551	10127	7,145	0.0394	0.4292	0.0169
14	0.65266	9885	6,452	0.0356	0.4012	0.0143
15	0.59458	9651	5,738	0.0316	0.3749	0.0118
16	0.53107	9423	5,004	0.0276	0.3504	0.0097
17	0.45848	9210	4,223	0.0233	0.3275	0.0076
18	0.38319	9003	3,450	0.0190	0.3060	0.0058
19	0.30772	8807	2,710	0.0149	0.2860	0.0043
20	0.24140	8622	2,081	0.0115	0.2673	0.0031
21	0.18328	8446	1,548	0.0085	0.2498	0.0021
22	0.13878	8278	1,149	0.0063	0.2335	0.0015
23	0.10657	8124	866	0.0048	0.2182	0.0010
24	0.08203	7975	654	0.0036	0.2039	0.0007
25	0.06294	7842	494	0.0027	0.1906	0.0005
26	0.05142	7712	397	0.0022	0.1781	0.0004
27	0.04195	7598	319	0.0018	0.1665	0.0003
28	0.03369	7489	252	0.0014	0.1556	0.0002
29	0.02815	7393	208	0.0011	0.1454	0.0002

30	0.02352	7303	172	0.0009	0.1359	0.0001
					Total	0.6266

a = Survival Probability * Exposure; b = $\frac{b}{\sum a}$; c = $\frac{1}{(1+3\%)^{age-0.5}}$; d = b*c

Table A-8
Exposure-weighted Discount Rate for **LTVs**
(**3%** Discount Rate, Lifespan 37 Years)

Age	Survival Probability	Exposure (VMT)	Weighted Exposure (VMT) (a)	Weighted Exposure Proportion (b)	Discount Factor Raw (c)	Discount Factor Exposure-Weighted (d)
1	1.00000	16145	16,145	0.0827	0.9667	0.0799
2	0.97760	15569	15,220	0.0779	0.9035	0.0704
3	0.96297	15000	14,445	0.0740	0.8444	0.0625
4	0.94276	14589	13,754	0.0704	0.7891	0.0556
5	0.93106	14187	13,209	0.0676	0.7375	0.0499
6	0.91519	13797	12,627	0.0647	0.6893	0.0446
7	0.89326	12726	11,368	0.0582	0.6442	0.0375
8	0.87002	12324	10,722	0.0549	0.6020	0.0330
9	0.84106	11937	10,040	0.0514	0.5626	0.0289
10	0.79626	11565	9,209	0.0472	0.5258	0.0248
11	0.74227	11210	8,321	0.0426	0.4914	0.0209
12	0.69156	10871	7,518	0.0385	0.4593	0.0177
13	0.64095	10546	6,759	0.0346	0.4292	0.0149
14	0.58334	10238	5,972	0.0306	0.4012	0.0123
15	0.53499	9944	5,320	0.0272	0.3749	0.0102
16	0.48613	9668	4,700	0.0241	0.3504	0.0084
17	0.44220	9404	4,158	0.0213	0.3275	0.0070
18	0.39760	9160	3,642	0.0186	0.3060	0.0057
19	0.35197	8928	3,142	0.0161	0.2860	0.0046
20	0.30919	8711	2,693	0.0138	0.2673	0.0037
21	0.26664	8513	2,270	0.0116	0.2498	0.0029
22	0.22780	8328	1,897	0.0097	0.2335	0.0023
23	0.20190	8162	1,648	0.0084	0.2182	0.0018
24	0.17500	8007	1,401	0.0072	0.2039	0.0015
25	0.15838	7873	1,247	0.0064	0.1906	0.0012
26	0.14520	7748	1,125	0.0058	0.1781	0.0010
27	0.13904	7644	1,063	0.0054	0.1665	0.0009
28	0.12500	7554	944	0.0048	0.1556	0.0007
29	0.11116	7479	831	0.0043	0.1454	0.0006
30	0.10277	7421	763	0.0039	0.1359	0.0005
31	0.09327	7376	688	0.0035	0.1270	0.0004
32	0.08347	7347	613	0.0031	0.1187	0.0004
33	0.07305	7335	536	0.0027	0.1109	0.0003
34	0.06191	7323	453	0.0023	0.1037	0.0002
35	0.05019	7310	367	0.0019	0.0969	0.0002

36	0.03839	7298	280	0.0014	0.0905	0.0001
37	0.02727	7285	199	0.0010	0.0846	0.0001
					Total	0.6076

a = Survival Probability * Exposure; b = $\frac{b}{\sum a}$; c = $\frac{1}{(1+3\%)^{age-0.5}}$; d = b*c

E. Comprehensive Component Unit Costs

Comprehensive costs include both economic cost components and quality-of-life valuations. The economic costs are cost that can be directly measured in economic terms. These cost components include productivity losses, property damage, medical costs, rehabilitation costs, congestion costs, legal and court costs, emergency services such as medical, police, and fire services, insurance administration costs, and the costs to employers. Quality-of-life valuations reflect loss-of-life or physical pain and are the intangible components of comprehensive costs. Table A-9 summarizes these cost components and corresponding unit costs in 2014 dollars. Unit costs are expressed on a per-person basis for all MAIS injury levels and per PDOV for PDOVs. The comprehensive costs for VSL of \$5.3, \$9.4, and 13.2 million are presented in the table. These comprehensive costs are specifically for crash avoidance countermeasures. Please consult the agency's report "The Economic and Societal Impact of Motor Vehicle Crashes, 2010"[176] for details.

[176] Blincoe, L. J., Miller, T. R., Zaloshnja, E., & Lawrence, B. A. (2015, May). The economic and societal impact of motor vehicle crashes, 2010. (Revised) (Report No. DOT HS 812 013). Washington, DC: National Highway Traffic Safety Administration

Table A-9
Summary of Comprehensive Unit Costs
(2014 $)

	PDOVs	**MAIS 0**	**MAIS1**	**MAIS2**	**MAIS3**	**MAIS4**	**MAIS5**	**Fatal**
Medical	$0	$0	$3,137	$12,835	$54,485	$152,761	$430,627	$12,682
EMS	$64	$41	$118	$240	$452	$910	$928	$979
Market Productivity	$0	$0	$2,955	$20,982	$69,733	$152,623	$365,915	$1,011,514
Household Productivity	$65	$49	$934	$7,702	$24,590	$40,689	$103,407	$314,218
Insurance Administration	$207	$155	$3,580	$5,058	$16,688	$30,646	$78,737	$30,748
Workplace	$67	$50	$370	$2,866	$6,260	$6,894	$12,021	$12,771
Legal	$0	$0	$1,283	$3,638	$13,464	$28,952	$89,795	$115,609
Travel Delay	$2,280	$1,535	$1,545	$1,572	$1,615	$1,638	$1,657	$6,200
Property Damage	$3,908	$2,923	$8,641	$9,239	$17,400	$17,727	$16,385	$12,172
Economic Cost*	$6,591	$4,753	$22,563	$64,132	$204,687	$432,840	$1,099,472	$1,516,893
QALYs (for $9.4 M VSL)	$0	$0	$24,581	$385,107	$860,345	$2,179,542	$4,858,903	$8,193,766
QALYs (for $5.3 M VSL)	$0	$0	$12,215	$191,373	$427,535	$1,083,090	$2,414,557	$4,071,766
QALYs (for $13.2 M VSL)	$0	$0	$35,966	$563,472	$1,258,820	$3,189,012	$7,109,338	$11,988,766
Comprehensive (for $9.4 M VSL)	$6,591	$4,753	$47,144	$449,239	$1,065,032	$2,612,382	$5,958,375	$9,710,659
Comprehensive (for $5.3 M VSL)	$6,591	$4,753	$34,778	$255,505	$632,222	$1,515,930	$3,514,029	$5,588,659
Comprehensive (for $13.2 M VSL)	$6,591	$4,753	$58,529	$627,604	$1,463,507	$3,621,852	$8,208,810	$13,505,659

*sum of above components
M: Million

APPENDIX B. RESPONSES TO COMMENTS ON THE ANPRM

NHTSA issued the ANPRM[177] and the accompanying V2V Readiness Report[178] on August 20, 2014. The ANPRM requested public comments on 57 questions to assist the Agency in formulating the proposed V2V rule.[179] These questions covered a variety of subjects including safety need, NHTSA's legal authority, technology technical issues, safety applications, potential acceptance, privacy, security, liability, potential cybersecurity threats[180], applicable standards, DSRC spectrum sharing, costs, and benefits.[181] This Appendix summarizes the Agency's responses to these comments. Please visit the DOT Docket at www.Regulations.gov. To search the NHTSA docket enter the docket number NHTSA-2014-0022 for the ANPRM and the individual comments.

Overall, the ANPRM included 12 questions directly related to the V2V benefits including the effectiveness of V2V safety applications and potential unintended consequence of the proposed rule. Specifically, the ANPRM included questions soliciting public comments on other potential approaches to obtain real-world data to evaluate effectiveness and whether the Agency identified the relevant potential crash scenarios for calculating benefits in the V2V Readiness Report.[182] The unintended consequence questions addressed possible harm resulting from the proposed V2V rule in the concept of a network good.[183] In addition, three questions solicited comments on the V2V cost estimates and on the development costs for apps.

[177] 79 FR 49270

[178] Docket No. NHTSA-2014-0022-0001

[179] 79 FR 49270, 49271

[180] *Id.* at 49273

[181] *Id. See also id.* at 49273-74

[182] *Id*. at 49271

[183] A good whose value to one consumer increases the more other consumers used the good. For example, Facebook, the value of Facebook to a user depends on how many other people use it. In other words, increasing the number of users creates a positive externality.

The Agency received more than 900 comments[184] from a diverse set of commenters.[185] The comments include automobile manufacturers/suppliers, trade associations, standards development organizations, safety advocacy groups, individual citizens, technology/communications companies, other State/Federal agencies, and privacy groups. Suppliers and car manufacturers generally supported the technology. However, they provided a competing view on whether to mandate the technology. They agreed that the benefits of the V2V technology will be relatively small until it reaches the critical penetration level, but they disagreed on how this critical level can be achieved (i.e., mandate[186] vs free-market[187]). They generally suggested that apps should not be mandated for concerns of lack of flexibility to innovate and to tailor the apps to meet customers demand. Comments from individual citizens overwhelmingly opposed V2V for fear of impacts on health and privacy.

The Agency has carefully reviewed the comments. However, due to the sheer volume of comments, it is not practical for the Agency to respond to each commenter; especially many individual commenters addressed the same issues and/or lacked specificity. This PRIA includes Agency responses to individual comments only when they specifically discuss the methodology of cost and benefit analyses and provided data to support their views. However, when feasible, the Agency responded collectively to comments on costs and benefits that lacked specificity. In addition, the Agency responded collectively to comments on the electromagnetic hypersensitivity (EHS) issue which many individual commenters raised as having health cost implications. The following summarizes Agency responses to the comments.

A. Comments on Benefit and Effectiveness

The Alliance of Automobile Manufacturers, Inc. (the Alliance), Fiat Chrysler Automobiles (Fiat-Chrysler), and the National Cable and Telecommunications Association (NCTA) provided in-depth discussions on the cost and benefit analyses. Note that some other car manufactures (e.g.,

[184] Vast majority are individual citizen and about 260 were anonymous.

[185] *See* Docket No. NHTSA-2014-0022

[186] American Honda Motor Inc. supported a mandate (NHTSA-2014-0022-0510)

[187] Fiat-Chrysler Automobiles (NHTSA-2014-0022-0281)

Ford, General Motor LLC[188]) submitted comments on these issues (i.e., costs and benefits) through the Alliance. The Agency responded through the Alliance discussion to these other individual car manufacturers.

From the Alliance of Automobile Manufacturers, Inc. (Alliance; NHTSA-2014-0022-0603)[189]

The Alliance commented on several key elements that OMB requires on regulatory analyses were not provided in the V2V Readiness Report, such as addressing market failure and alternative regulatory approaches. Furthermore, the Alliance recommended the future regulatory analyses on V2V to include additional benefit and cost estimates. They suggested we include additional benefit estimates to address (1) reduction of traffic congestion, (2) energy savings, and (3) environment benefits. In addition, they suggested we include additional cost estimates to address (1) loss of perceived privacy, (2) opportunity costs of using the spectrum for other use, and (3) increase in litigation transaction costs.

Response

The agency is aware of the limitations of the V2V Readiness Report which was initially intended to be a research report, not a full blown regulatory analysis. This PRIA follows the OMB and DOT guidance on regulatory analyses and includes all required elements as suggested by the Alliance. In addition, the PRIA discusses the additional benefits and costs as non-quantified benefits and non-quantified costs in the Benefits and Costs chapters, respectively. However, besides the proposal the PRIA examines a single regulatory alternative since we determined that other potential alternatives would hinder speedy development of V2V technologies. Without speedy market penetration, the benefits of V2V would be expected to be realized much later. For benefits, this PRIA included energy, congestion, and environment benefits as suggested. These benefits are categorized as congestion benefits (or costs) which included the estimated

[188] NHTSA-2014-0022-0938

[189] Ford Motor Company also commented on this topic through the Alliance (NHTSA-2014-0022-0946). Ford stated that the benefit estimates seem reasonable.

reduction of greenhouse gas and pollutant emissions due to vehicle delay hours and added fuel consumption that resulted from congestion caused by crashes. However, the PRIA does not quantify other suggested cost elements. First, the agency did not quantify perceived privacy loss because the perception of and the level of sensitivity to privacy depends on the type of information collected and how it would be used. There are no standardized economic values that can be associated with different levels of sensitivity.

Second, with respect to spectrum use, please see the discussion in Chapter VII, Section F of this document.

Finally, as for a possibly increase in litigation costs, the agency believes that the V2V technology is expected to avoid up 615,000 crashes and thus would reduce the overall burden imposed on legal systems.

From the Fiat Chrysler Automobiles (Fiat-Chrysler, NHTSA-2014-0022-0281)

Fiat-Chrysler commented on the costs, effectiveness of the system, and benefit estimation methodology. They stated that the costs and benefits estimated in the ANPRM do not realistically represent the technology's effectiveness or cost burden. For costs, they stated that the cost model is based on multiple assumptions, many of which are arbitrary because no field-data is available. The ANPRM has not incorporated costs required to address malfunction, maintenance, replacement, or check-up expenditures. Furthermore, Fiat-Chrysler stated that the agency has not considered the variability of cost estimates.

For the system effectiveness estimates, Fiat-Chrysler stated that the ANPRM did not consider the limitation of the technology. Specifically, Fiat-Chrysler stated that the ANPRM did not address the impact of inaccurate information (i.e., erroneous messages) and message congestion on system effectiveness. Furthermore, they stated that the ANPRM did not explain whether and when these limitations can be addressed in the future. For IMA crash avoidance effectiveness, Fiat-Chrysler stated that they believe that it was derived by separating the 4 meter cases from the 3-5 meter cases in the NHTSA analysis. They said that doing so may induce additional errors. For crashworthiness effectiveness, Fiat-Chrysler stated that injury probability curves that were used to estimate the crashworthiness benefits of IMA should be based only on crashes that resemble these scenarios and should not include crashes such as rollover, single vehicle crashes, frontal crashes, rear crashes, etc., that will distort the estimation. They also raised the issue on the larger variability surrounding the crashworthiness reduction rates and questioned its statistical significance.

For benefit methodology, Fiat-Chrysler stated that a meaningful benefit analysis should evaluate the lower and higher bounds considering all the possible sources of variability. Or , at least, it should have acknowledged that the low/high bound suggested do not consider the variance of all the steps used in the procedure performed and may be a significant miss-estimation.

Response

The V2V Readiness Report accompanying the ANPRM was not intended to be a comprehensive economy analysis. Unlike the V2V Readiness Report, the PRIA, following OMB's guidance, first provides primary cost and benefit estimates. Then, the PRIA conducts sensitivity and uncertainty analyses to address the possibility of variability for cost and benefit estimates.

Specifically, in the uncertainty analysis, we used a conservative system effectiveness to estimate the benefits. This approach, we believe, considers the impact of technology limitations and possible message congestion. For example, for the IMA crash avoidance effectiveness, we disagree with Fiat-Chrysler that the IMA effectiveness was derived by separating the 4 meter cases from the 3-5 meter cases. For the IMA effectiveness, we considered the design restrictions and the possible impact scenarios. We specifically separated the 3, 4, and 5 meter cases. The approach resulted in a wider effectiveness range than when these cases are combined. As a result, the approach, together with the uncertainty analysis, also addresses the uncertainty around the effectiveness.

For the crashes that were used to derive the probability curves for IMA, we disagree with Fiat-Chrysler that we include non-relevant crashes such as rollover, single vehicle crashes, frontal crashes, rear crashes, etc. For the crashes, we only included IMA cases which did not include rollovers, single-vehicle crashes, and other non-relevant crashes. However, as we stated in the V2V Readiness Report, due to the sample size issue, we did not derive the probability curves separately for IMA-M and IMA-S crashes. We understand that the large variability surrounding the crashworthiness reduction rates raised uncertainty issues. However, the crashworthiness benefits primarily were from MAIS 1 injuries and from the IMA crashes. They comprised about 4 to 8 percent of the overall V2V benefits when all vehicles had V2V technology. In the first 10 years due to low overall V2V app penetration rates, crashworthiness benefits were insignificant and thus would not impact on the breakeven and the cost-effective conclusions of the proposed rule. Furthermore, the variability of crashworthiness effectiveness was addressed in the uncertainty analysis of this PRIA.

From the National Cable and Telecommunications Association (NCTA, NHTSA-2014-0022-0932)

NCTA recommended the following actions in their comments to the ANPRM:

(1) Avoid taking any action in this proceeding that would prevent the FCC from ensuring that valuable 5.9 GHz spectrum is put to its highest and best use, or that fails accurately to account for the full value of 5.9 GHz spectrum, as NHTSA must do under the Presidential and OMB directives.

(2) Continue to recognize that the V2V safety warning operations at issue in this ANPRM are substantially different from other possible DSRC applications. NHTSA is not considering mandating these other potential commercial applications and should recognize that existing communications technologies, such as Wi-Fi, can enable these applications without NHTSA's intervention.

(3) Amend its cost-benefit analysis to more accurately reflect the true costs and benefits of a V2V mandate, including accounting for stymied investment, innovation, and competition in alternative crash-avoidance technologies, and the opportunity cost of foregone Wi-Fi spectrum for millions of American consumers.

Specifically for the cost-benefit analysis, in the cost side, NCTA stated that the costs of mandating a particular crash-avoidance technology such as V2V vastly exceed the benefits when the opportunity cost of foregone Wi-Fi spectrum is taken into account. NCTA states that the unlicensed wireless sector—with Wi-Fi leading the way—is central to U.S. economic growth and innovation. One recent study estimates that unlicensed spectrum generated $222 billion in value for the U.S. economy in 2013 and contributed $6.7 billion to the U.S. Gross Domestic Product ("GDP") over the same period. A follow-up study estimates that by 2017, if consumers and businesses have access to adequate spectrum to support growth, unlicensed spectrum will generate $547.22 billion in economic surplus and add $49.78 billion to the GDP. Wi-Fi networks in particular—which rely on unlicensed spectrum in the 2.4 GHz and 5 GHz bands—provide several significant public interest benefits: (1) providing millions of consumers with fast, reliable Internet access, inside and outside the home; (2) providing businesses with broadband connectivity, as well as a value-added service that they can provide to their employees and customers; (3) connecting schools and libraries to the Internet, as demonstrated in the President's ConnectED program; (4) encouraging the development of new business models; (5) permitting consumers to manage their wireless 3G/4G data plan usage by relying on Wi-Fi as a supplement to licensed networks, while helping to alleviate overburdened cellular networks through Wi-Fi offloading; (6) supporting the development of the Internet of Things, including the connected home and machine-to-machine industrial applications; and (7) improving efficiency of farming, industrial, and manufacturing enterprises through the use of precision tools and inventory systems. Just a fraction of these Wi-Fi-related economic benefits alone in 2013 amounted to more than $91.5 billion in economic surplus and added more than $4.5 billion to the GDP. All of this depends on access to enough spectrum to meet consumer demand.

Moreover, NCTA stated that the cost of a mandate could also be greater than NHTSA anticipated because the following reasons:
(a) A Government mandate will stifle alternative technologies and undermine innovation and competition. A mandate will likely squash non-V2V crash-avoidance technologies as research and development and production shift to focus on DSRC V2V.
(b) A mandate that precludes unlicensed coexistence in the 5.9 GHz will impair the growth of unlicensed technologies to meet growing consumer needs, and would undermine the development of future technologies, particularly 802.11ac Wi-Fi.

For benefits, NCTA stated that the NHTSA overestimates the benefits of IMA and LTA for the following reasons:

(a) NHTSA does not plan to require manufacturers to include LTA and IMA and not all auto manufacturers may offer these specific features.

(b) NHTSA's analysis does not account for the advancement of existing technologies or the development of new technologies that could solve the same problems that NHTSA claims only V2V can fix. It is likely over the span of the thirty-seven years that NHTSA believes it will take before V2V is widely deployed; existing sensor technologies will improve and could likely evolve to provide many of the benefits that NHTSA claims are exclusive to V2V.

(c) NHTSA fails to recognize that because of V2V requires all cars to incorporate DSRC radios, V2V is less beneficial than other existing crash-avoidance technologies. Sensor-based crash-avoidance technologies are already on the road today, saving lives and reducing injuries and property damage, without requiring a thirty-seven-year phase-in before yielding benefits. The phase-in period and the requirement that all other actors on the road must use the same equipment in order for V2V to function undermine the benefits that V2V can offer.

Finally, NCTA submitted a technical paper by the University of Colorado to show an approach of optimizing DSRC efficacy and spectrum utility in the 5.9 GHz band. The recommended approach is to use three dedicated 10 MHz channels in the upper frequency of the 5.9 GHz band and free up the remaining 45 MHz for unlicensed Wi-Fi use.

Response

For spectrum use and opportunity costs please see the discussion in Chapter VII, Section F of this document. Although the proposed rule does not require IMA and LTA, we expect that the manufacturers will develop these crash avoidance safety apps as they did for vehicle-resident systems. First, the cost of implementing safety app is marginal compared to the cost of the hardware. Second, the success of the app market on the Apple and Google platforms is due to the prevalence of smart phones, tablets, and other mobile devices. Mandating V2V provides the hardware platform that is necessary and critical to the development and success of safety apps. That said, we do not envision a similar application "marketplace" in the V2V context as for Apple, Google, or other smart phone-type platforms, at least not immediately. At the beginning, we would expect vehicle and V2V device manufacturers to be the only entities offering applications.

Many automobile manufacturers indicated that V2V and vehicle-resident technologies are complementary. They can use the information in BSMs to augment their vehicle-resident safety systems and use each technology in different crash scenarios. Therefore, the agency does not expect that V2V would delay or discourage the adoption of vehicle-resident technologies. The proposed rule does not preclude spectrum sharing. Thus, the agency does not believe that the proposed rule would stifle alternative technologies such as Wi-Fi and undermine innovation and competition.

As for benefits, the agency used the crashes from 2010-2012 (2010-2014 in this PRIA) the date where the crash levels were at the lowest. Our GES and FARS show that crashes and fatalities start to increase in 2011. Our baseline for benefit estimates was limited to IMA and LTA crashes. Currently, the agency does not expect the vehicle-resident systems can adequately address these crashes. Thus, the baseline did not need to be further adjusted to consider the vehicle-resident systems. As discussed above, the implementation of IMA and LTA has a marginal cost and several manufacturers indicated that IMA and LTA are already in their development plan. Further, the agency has limited its benefit estimate to these two technologies while other beneficial and safety enhancing uses are likely. Therefore, the agency believes we did not overestimate the benefits. NHTSA recognizes that V2V requires all cars to incorporate DSRC radios. This does not imply that V2V is less beneficial than other existing crash-avoidance technologies. Specifically, vehicle-resident systems are not adequate to address IMA and LTA crashes. We believe that NCTA miss-interpreted the ANPRM results. It would take thirty-seven-years to reach 100 percent penetration for all on-road light vehicles. It is not that it will take 37 years before V2V is widely deployed. As shown in the PRIA, the proposed rule would start to accrue benefits two years after the implementation of the proposal and would breakeven within 11 years of implementation. The proposed rule would be cost-effective by the 5^{th} model year for new vehicle purchasers.

B. **Comments on Costs**

From the Alliance of Automobile Manufacturers, Inc. (Alliance; NHTSA-2014-0022-0603)[190]

The Alliance suggested the agency include additional cost estimates to address (1) loss of perceived privacy, (2) opportunity costs of using the spectrum for other use, and (3) increase in litigation transaction costs.

Response

Please see the above response to the Alliance' comments on costs above.

From the National Cable and Telecommunications Association (NCTA, NHTSA-2014-0022-0932)

NCTA stated that the costs of mandating a particular crash-avoidance technology such as V2V vastly exceed the benefits when the opportunity cost of foregone Wi-Fi spectrum is taken into account. The cost of a mandate could also be greater than NHTSA anticipated because the following reasons:

(a) A Government mandate will stifle alternative technologies and undermine innovation and competition. A mandate will likely squash non-V2V crash-avoidance technologies as research and development and production shift to focus on DSRC V2V.

(b) A mandate that precludes unlicensed coexistence in the 5.9 GHz will impair the growth of unlicensed technologies to meet growing consumer needs, and would undermine the development of future technologies, particularly 802.11ac Wi-Fi.

Response

Please see our response to NCTA's and the Alliance' comments on costs above.

From the National Motorists Association (NMA) and from other citizens

[190] Ford Motor Company also commented on this topic through the Alliance (NHTSA-2014-0022-0946). Ford stated that the benefit estimates seem reasonable.

The NMA commented that the estimated cost of $350 per vehicle by 2012 is very burdensome for many new car buyers and for vehicle owners faced with retrofit packages.[191] NMA stated that much of the cost of implementation should be offset by lower vehicle insurance premiums or be financed directly by the insurance industry. NMA also posed a question whether V2V would put a damper on broader deployment of vehicle-resident safety technologies and provide narrower and perhaps less certain overall benefits than estimated. In addition, several comments from individual citizens also stated that the expected increase in cost will generate unnecessary burdens on consumers.

Response

The Agency understands that the proposed rule would increase the cost of purchasing a vehicle. In the PRIA, the Agency estimated the increased costs would range $249 to $351 per vehicle. Given that V2V technology has tremendous potential to save lives and reduce environment and energy impacts, consumers will share these benefits as long as they keep the vehicles. The Agency considers that the V2V technology and vehicle-resident safety technologies are complementary. Some manufacturers have already planned to deploy the V2V technology, voluntarily. In addition, some manufacturers also consider V2V is an integral part of automated vehicles, a goal that the industry is moving towards. Therefore, the Agency does not believe mandating V2V will damper the deployment of vehicle-resident safety.

C. Comments on Electromagnetic Hypersensitivity (EHS)

From other commenters

Commenters cited many EHS related symptoms including but limited to heart attack, concentration difficulties, confusion, fatigue, visual and judgement errors, etc. These comments highlight the potential relationship of the V2V technology to EHS. The commenters stated that the premise that this technology makes driving safer is false. They stated that it will create mental confusion, fatigue, and/or visual misperception, and will effect judgement that will result in many more accidents and deaths. The EMR Policy

[191] NHTSA-2014-0022-0598

Institute[192] expressed similar concerns stating that NHTSA should postpone this rulemaking until the FCC changes their guidelines regarding human radiation exposure to wireless communications.

Response

After reviewing these comments, the Agency has conducted a literature review to better understand electromagnetic radiation and its relationship to the symptoms of EHS.

At the time of the publication of the NPRM, the Agency has not uncovered any concrete relationship between V2V electromagnetic radiations to EHS. The FDA also stated that most studies conducted to date show no connection between certain health problems and exposure to radio frequency fields of cell phone use. The literature search shows that no one has successfully replicated (and confirmed) the few studies that have claimed this connection.[193] Nevertheless, the Agency will continue to monitor new developments by experts in this field. In addition, the Agency will closely follow the efforts of the Radio Frequency Inter Agency Work Group (RFIAWG) which may yield potential future guidance for wireless device deployment and usage.

[192] Docket No. NHTSA-2014-0022-0682

[193] Radiation-Emitting Products, "Current Research Results," http://www.fda.gov/Radiation-EmittingProducts/RadiationEmittingProductsandProcedures/HomeBusinessandEntertainment/CellPhones/ucm116335.htm, last accessed: June 3, 2015.